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88-04

FALLOUT RADIATION EFFECTS ANALYSIS METHODOLOGY

MARCH 31, 1988

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OFFICE OF THE MANAGER,
NATIONAL COMMUNICATIONS SYSTEM
WASHINGTON, D.C. 20305

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Fallout radiation is viewed by the weapons effects community as a potentially serious impediment to maintaining or restoring critical National Security Emergency Preparedness (NSEP) telecommunication capabilities in a nuclear environment. The Electromagnetic Pulse (EMP) Mitigation Program is designed, in part, to identify the survival probability (survivability) of the nation's NSEP telecommunication infrastructure against fallout radiation effects. The OMNCS is developing a balanced approach consisting of fallout radiation stress tests on the electronic piece-parts and the use of estimated performance measures of telecommunication network elements in network simulation models to predict user connectivity levels.

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FALLOUT RADIATION EFFECTS ANALYSIS METHODOLOGY

MARCH 1988

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FOREWORD

The National Communications System (NCS) is an organization of the Federal Government whose membership is comprised of 23 Government entities. Its mission is to assist the President, National Security Council, Office of Science and Technology Policy, and Office of Management and Budget in:

o   The exercise of their wartime and non-wartime emergency functions and their planning and oversight responsibilities.

o   The coordination of the planning for and provision of National Security/Emergency Preparedness communications for the Federal Government under all circumstances including crisis or emergency.

Fallout radiation is viewed by the weapons effects community as a potentially serious impediment to maintaining or restoring critical National Security Emergency Preparedness (NSEP) telecommunication capabilities in a nuclear environment. The OMNCS' Electromagnetic Pulse (EMP) Mitigation Program is designed, in part, to identify the survival probability (survivability) of the nation's NSEP telecommunications infrastructure against fallout radiation effects. The OMNCS is developing a balanced approach consisting of fallout radiation stress tests on the electronic piece-parts and the use of estimated performance measures of telecommunication network elements in network simulation models to predict user connectivity levels.

Comments on this TIB are welcome and should be addressed to:

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EXECUTIVE SUMMARY

Fallout radiation is viewed by the weapons effects community as a potentially serious impediment to maintaining or restoring critical National Security Emergency Preparedness (NSEP) tele-communication capabilities in a nuclear environment. The OMNCS' Electromagnetic Pulse (EMP) Mitigation Program is designed, in part, to identify the survival probability (survivability) of the nation's NSEP telecommunications infrastructure against fallout radiation effects. The OMNCS is developing a balanced approach consisting of fallout radiation stress tests on the electronic piece-parts and the use of estimated performance measures of telecommunication network elements in network simulation models to predict user connectivity levels.

In this work, the EMP Mitigation Program evaluates a methodology for addressing the effects of nuclear weapon generated fallout radiation on telecommunication network assets. While earlier work set forth this methodology, this investigation applies actual vulnerability test results to predict equipment survival probability and provides a basis for further radiation effects assessments. The implementation of this analytical method provides the OMNCS with the ability to assess radiation effects on the nation's NSEP telecommunications infrastructure. Results of this study enhance the understanding of the degradation incurred by telecommunication network elements (switches and transmission facilities) as a result of fallout radiation exposure.

INVESTIGATION

This investigation has three main objectives:

- Extend prior work on network performance character-ization through the development and demonstration of the radiation effects methodology postulated in Ref-erence 1, using the available data collected under the 5ESS Radiation Hardness Assessment Program (RHAP), Reference 3 and Reference 4.

- Develop an improved understanding of the fallout radiation testing needs of the OMNCS and determine the sensitivity of results with variations in test data distribution.

- Determine the additional OMNCS activities required to characterize the performance of the NSEP telecommunica-tions infrastructure when subjected to a fallout radiation environment.

The results obtained in this investigation were studied to test the following propositions related to the performance of the NSEP telecommunications infrastructure in a fallout radiation stressed environment:

- Fallout radiation could significantly affect the overall performance of PSN component resources.

- Additional radiation piece-part test data may be required to adequately assess all critical PSN telecommunications equipment.

- Judicious testing of selected piece-parts could significantly reduce the observed variance of equipment survivability results.

It is noteworthy that the statistical confidence of the survival estimates presented in this report are dictated by the limitations of the available piece-part test data.

FALLOUT RADIATION NETWORK LEVEL APPROACH

The network level approach for determining fallout radiation effects on network performance contains four steps:

- Assess equipment survivability

- Specify network topology

- Specify fallout radiation levels over network equipment locations using a radiation dispersion model

- Characterize network performance using the Network Connectivity Analysis Model (NCAM).

The first, and most difficult step, and the focus of this report, assesses the effects of fallout radiation on network telecommunications equipment. In the absence of detailed analyses, where circuit diagrams might be employed, the first step seeks to optimize the available data through analytic equipment survivability modeling. Step two identifies the topology of the network under investigation. The third step uses a radiation dispersion model to specify radiation dosage levels at particular network equipment. Based on data obtained in steps one through three, the last step models and simulates the connectivity of a radiation-exposed network. Approaches for accomplishing Steps 2-4 have been identified in Reference 1 and will therefore not be addressed in detail hereinafter.

EQUIPMENT RADIATION EFFECTS METHODOLOGY

Based on available data collected, equipment survivability relative to fallout radiation exposure can be assessed by

implementing strategies similar to those applied in the EMP equipment survivability studies (Reference 6 and Reference 7). First, a unique survival probability distribution is estimated using the Bayesian Survivability Model (BSM) for each critical piece-part family. Second, the individual survival probability distributions of the piece-part families are combined to develop equipment survival probability distributions. Along with network topology and radiation dispersion patterns, these equipment radiation effects may be used by the OMNCS to characterize network performance.

In addition, the method presented supports quantitative analyses that specify which telecommunications equipment, components, or piece-parts should be tested and/or analyzed for radiation susceptibility. In addition, this method enables the OMNCS to locate the point of diminishing returns, where additional testing would provide little additional insight into predicting the connectivity of networks exposed to fallout radiation.

Equipment Survivability Application

For this investigation, available 5ESS piece-part data are used to model the radiation response of each technology family. The piece-part fallout radiation test data used in this investigation were collected under the 5ESS RHAP (Reference 3 and Reference 4) and reflect actual fallout radiation test results. Using this data the estimated survivability of the network equipment (5ESS switch) is the convolution of estimated survival probabilities of each different technology family. The survival probability of the switch is calculated using a Monte Carlo procedure.

This application assumes that all technology families are equally represented in the switch and critical for successful equipment operation; all of the technology families must survive for the switch to survive. Piece-part technologies are combined into families based on similar radiation response characteristics and similar piece-part constructions. Using the results of radiation piece-part data for each technology family, a series of Cumulative Distribution Function (CDF) and Probability Density Function (PDF) curves are developed that describe the technology family survivability against fallout radiation. Furthermore, combining piece-part families with small sample sizes and similar distributions decreases the variance in the system survival probability estimates.

A separate curve is developed for each range of radiation dosage levels to which telecommunications equipment is exposed. The eight "bins" below describe radiation dosage levels to which

the equipment and its piece-parts are exposed:

        0-500 Rads(Si)
        500-1k Rads(Si)
        1k-5k Rads(Si)
        5k-10k Rads(Si)
        10k-20k Rads(Si)
        20k-30k Rads(Si)
        30k-40k Rads(Si)
        40k-50k Rads(Si).

One Rad(Si) equals 10^{-5} joules of energy absorbed in 1 gram of silicon mass. These bins have been created arbitrarily, but with and eye towards ensuring that the failures of the piece-part technology families are detected. Within each bin (e.g. 500-1k Rads(Si)), the piece-part technology family survival probability, described by its Bayesian posterior survival probability distribution, is estimated using the BSM. As a result, each piece-part technology family has eight survival distribution curves corresponding to the eight fallout radiation dosage level bins.

Exhibits ES-1 and ES-2 are the CDF and PDF curves representing the survivability distributions of two 5ESS technology families, the CMOS Digital 4k/16k SRAM and the CD4000. These distributions are calculated using the BSM and represent the survivability of the technologies when exposed to a radiation dosage level between 500-1k Rads(si). The mean and standard deviation of the PDFs may be calculated for each of the families to provide an average survivability and a measure of the survivability variation within a technology family.

Exhibit ES-1
CDF Survival Curve for 4k/16k SRAM, 500-1k Rads(Si) Bin
(113 survivals out of 119 samples)

ES-4
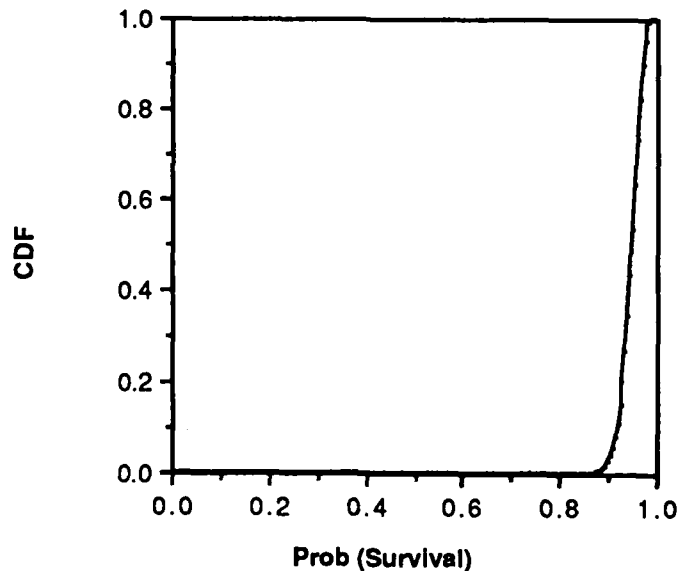
Exhibit ES-2
PDF Survival Curve for 4k/16k SRAM, 500-1k Rads(Si) Bin
(57 survivals out of 59 samples)
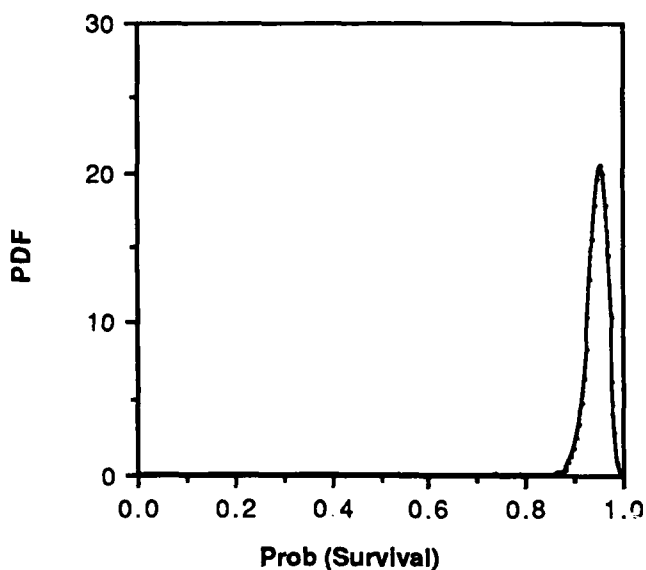
The PDF curves estimating the 5ESS switch survivability are shown in Exhibits ES-3 and ES-4. These equipment level survivability curves are based on the survivability distributions of the piece-part families which comprise the equipment, such as the distributions shown in Exhibits ES-1 and ES-2. As shown in Exhibit ES-3, the effects of fallout radiation are small at low dosage levels (0-500 Rads(Si)), which results in a high switch survivability prediction. More pronounced variations in equipment performance were exhibited for the radiation dosage in the 1k-5k Rads(Si) bin as illustrated in Exhibit ES-4. In Exhibit ES-4, the switch survivability decreases rapidly in the 1k-5k Rads(Si) radiation dosage level bin because all test data on piece-parts in the HMOS piece-part family fail in this bin.

Effects of Increased Test Data Sample Size

The small test data sample size applied in this analysis limits the accuracy of the survivability predictions for the piece-part technologies and further decreases the accuracy of the switch survivability predictions. Major findings of this investigation, shown in Exhibits ES-5 through ES-7, indicate that increasing the sample size reduces the variance of the predicted piece-part survivability and switch survivability.

Exhibit ES-3
PDF Survival Curve for the 5ESS Switch, 0-500 Rads(Si) Bin

PDF Survival Curve for the 5ESS Switch, 1k-5k Rads(Si) Bin

PDF

120

100

80

60

40

20

0

0.0   0.2   0.4   0.6   0.8   1.0
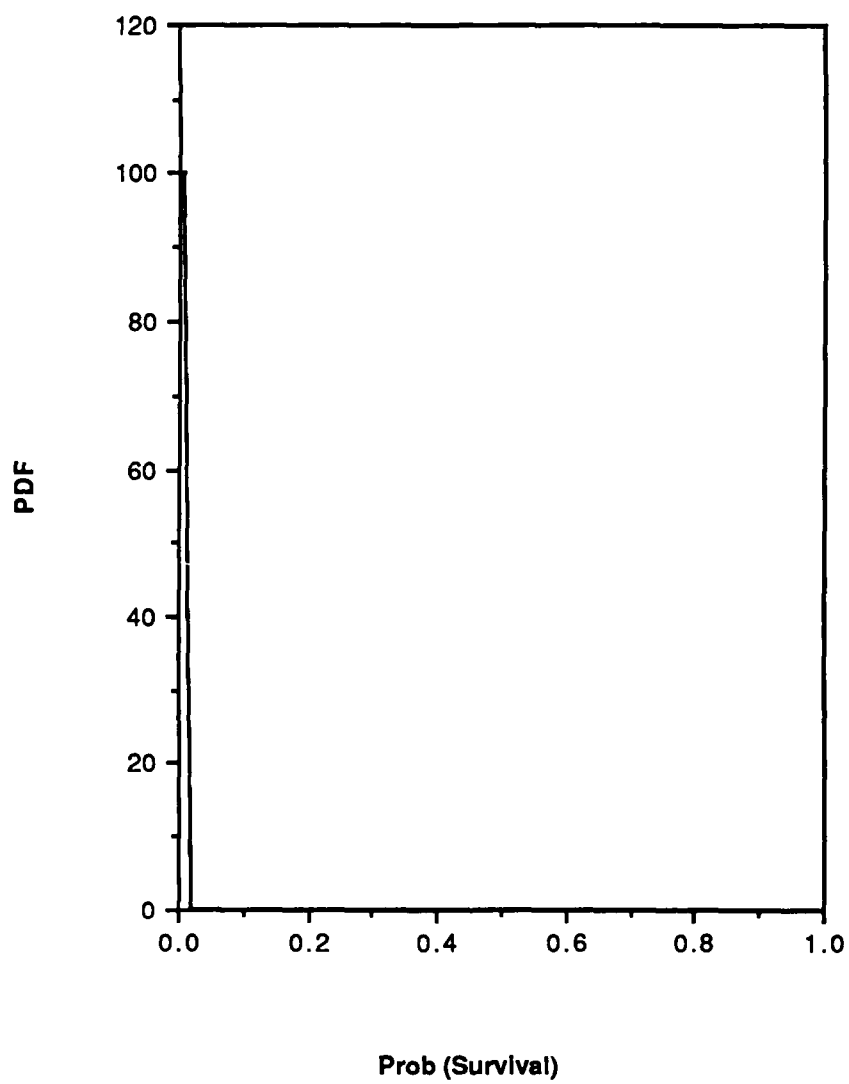
Prob (Survival)

Exhibit ES-5 is the PDF curve for the CMOS 54HC technology family in the 10k-20k Rads(Si) bin and shows how increasing the sample size reduces the standard deviation of the predicted survival probability. The graph is generated by hypothetically increasing the sample size by a factor of 2, 5, 10, and 20, while also increasing the number of survivals by the same proportions.

Exhibit ES-5
Effects of Increased Sample Size on the
PDF Survival Curves, 54HC Family
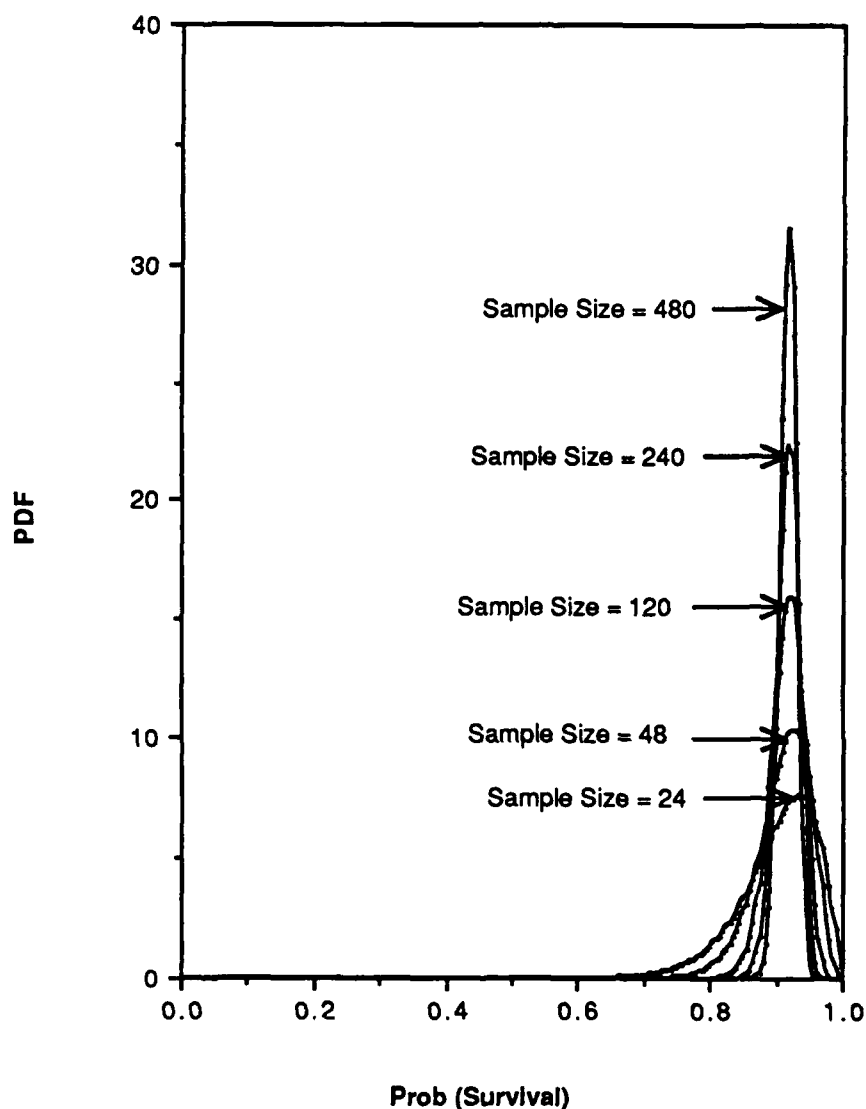
Exhibit ES-6 plots the standard deviations of the PDF curves in Exhibit ES-5. By reducing the variance of the technology family distribution, the accuracy of the equipment survivability estimation is increased. Exhibit ES-6 indicates that the standard deviations decrease rapidly with an increase in sample size. Markedly improved results may be obtained by increasing the sample size to approximately 200 samples.

Exhibit ES-6
Standard Deviation vs. Sample Size of
54HC Family PDF Survival Curves
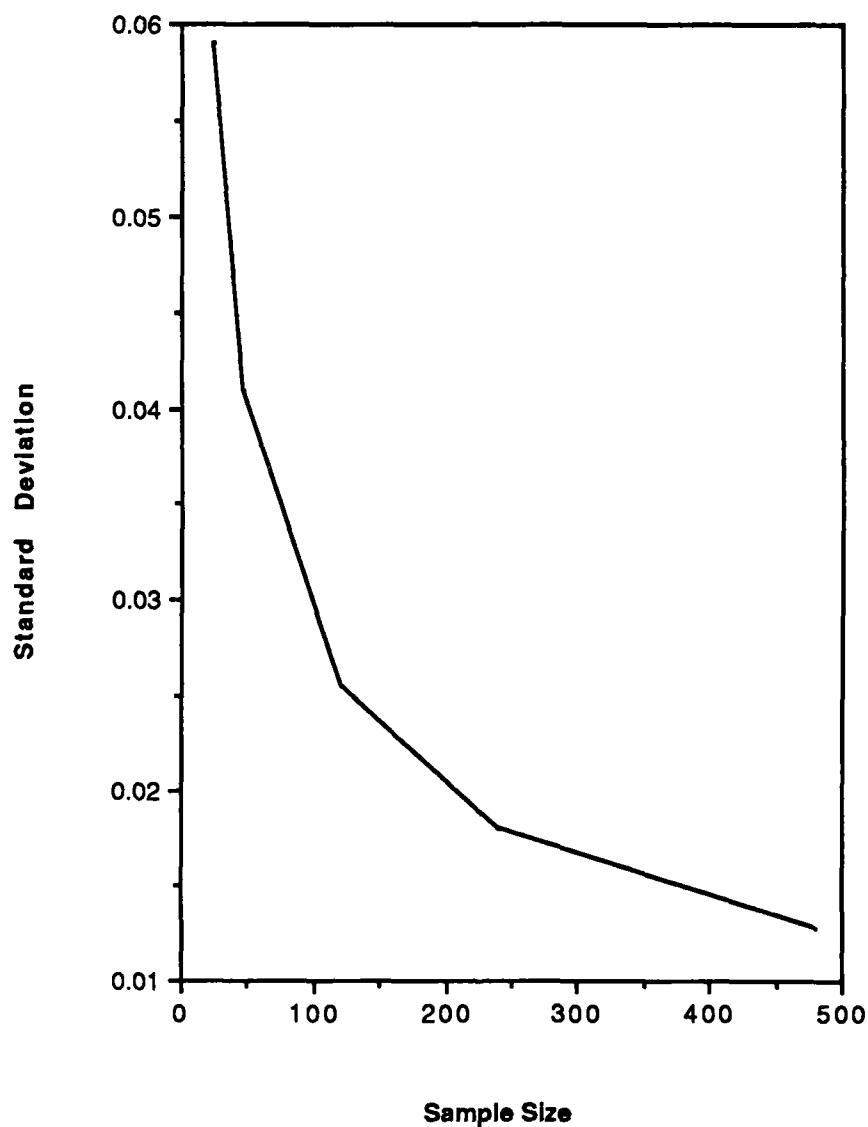
Exhibit ES-7 shows the predicted 5ESS switch survivability based on the survivability of its piece-parts. More importantly, Exhibit ES-7 illustrates the significance of obtaining additional radiation data for specific technology families. Presently, the NMOS piece-part family has a sample size of only one. This results in a wide variance for the 5ESS switch fallout radiation survivability distribution as indicated by its irregular shape. If the sample size were increased to 200 while maintaining a proportional number of survivals, the standard deviation of the new switch survivability estimation would be reduced relative to that of the initial switch survivability.

Exhibit ES-7
Effect of Increased Sample Size of NMOS family
(Small Sample Size) on the 5ESS Switch Survivability
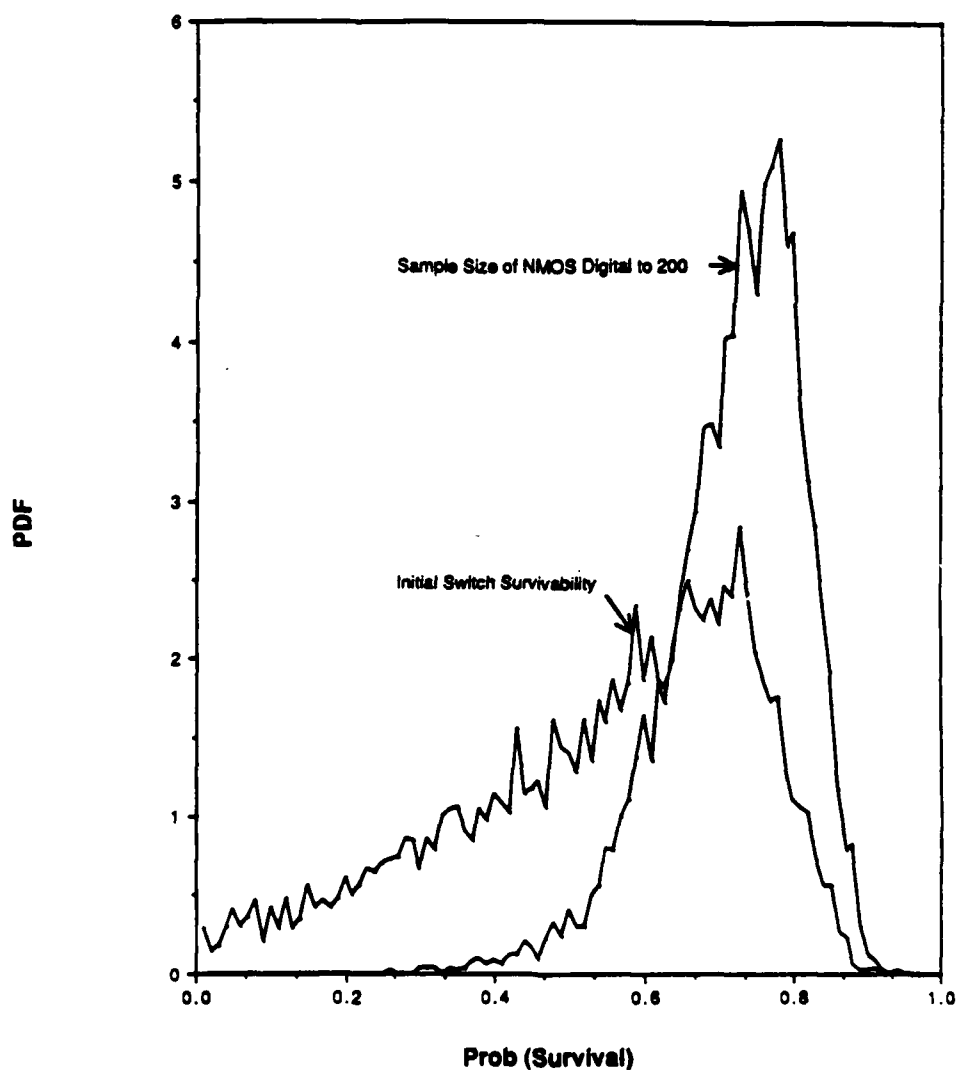
CONCLUSIONS

The primary conclusion of this work is that given limited available data, the proposed method can predict fallout radiation effects on network telecommunications equipment. This is important for applications in equipment performance and network performance modeling in simulated fallout radiation environments. Along with enhanced radiation effects performance modeling, it is significant that by increasing the sample size to approximately 200 samples, the statistical quality of survivability predictions can be significantly improved. Within the given initial conditions that bound this study, the major findings further suggest that the proposed analytical techniques for estimating network element performance, in conditions of fallout radiation stress, provide an appreciable cost/benefit advantage over exhaustive experimental testing.

RECOMMENDATIONS

Based on the positive results presented in this report, the OMNCS should continue the development of the modeling techniques and the expansion of the data bases required to support the radiation assessment methodology that has been presented. The future efforts should focus on the following areas:

- Continue the development of modeling techniques. The methodology presented establishes the framework for completing the network level assessments of radiation effects. Future efforts should focus on developing modeling techniques to enhance the accuracy and flexibility of the existing methodology. More statistically rigorous methods for combining technology families, such as multivariate statistical analysis methods (Reference 10 and Reference 11), should be evaluated for inclusion in the methodology.

- Collect the available data to support radiation effects assessments. The data used in this effort were used because they had been collected under a previous program for the OMNCS. Much larger quantities of component data are readily available, and could be entered into a data base for the OMNCS to support the radiation effects assessments. The OMNCS should also continue to work with equipment vendors to identify those technologies that are used in the telecommunication assets that support NSEP initiatives.

- Develop guidelines for the collection of test data. While large quantities of data are readily available, it may be necessary for the OMNCS to support limited testing programs to provide critical data for some network assessments. As part of the development of this methodology, the OMNCS should identify testing

requirements that are consistent with the goals and objectives of this program. Such requirements would include appropriate selection of devices to be tested and appropriate sample sizes.

- <u>Prioritize system assessment efforts</u>. The OMNCS should prioritize future telecommunications asset assessment efforts to focus on those areas that will provide the most information about network level effects. To accomplish this, the OMNCS should perform sensitivity analyses on the network level models to identify those parameters that have the greatest impact on network level results.

1.0 INTRODUCTION

National Security Decision Directive (NSDD) 97 and Executive Order (E.O.) 12472 require that the Office of the Manager, National Communications System (OMNCS) take actions to ensure the continued availability of National Security Emergency Preparedness NSEP telecommunication capabilities in the event of a nuclear war. Fallout radiation is viewed by the weapons effects community as a potentially serious impediment to maintaining or restoring NSEP telecommunication capabilities in a nuclear environment. The OMNCS' Electromagnetic Pulse (EMP) Mitigation Program is designed, in part, to identify the survivability of the nation's telecommunications infrastructure against fallout radiation effects. The OMNCS is developing a balanced approach consisting of fallout stress tests on the electronic piece-parts and the use of estimated performance measures of telecommunication network elements in network simulation models to predict user connectivity levels.

This report focuses on a method for addressing the effects of nuclear weapon generated fallout radiation on telecommunication network assets. The implementation of this analytical method provides the OMNCS with the ability to assess radiation effects on the nation's NSEP telecommunications infrastructure. Results of this study enhance the understanding of the degradation incurred by telecommunication network elements (switches and transmission facilities) as a result of fallout radiation exposure.

1.1 BACKGROUND

A major objective of the EMP Mitigation Program is to

analyze and, where appropriate, lessen the potential adverse effects of fallout radiation on the nation's telecommunications infrastructure. The program focuses on the telecommunication resources of the Public Switched Networks (PSNs), specifically those PSN elements envisioned to support the National Level NSEP Telecommunications Program (NLP). The nation's public networks represent the largest and most promising collection of communication resources capable of meeting the wide range of government emergency communication needs. In accordance with the objectives of the EMP Mitigation Program, the OMNCS has developed a preliminary method for assessing network level fallout radiation effects (Reference 1). The OMNCS treats that methodology as a foundation on which to base further study to determine the network level effects of fallout radiation on the PSN. The network level approach to assessing the effects of fallout radiation on PSN resources supports quantitative estimations of service degradation that NSEP telecommunication users can experience as a result of fallout radiation. The OMNCS network level approach can be used by the National Communications System (NCS) member organizations to determine trade-offs in telecommunications cost, performance, and capability.

An initial study addressing network level effects of fallout radiation is presented in Reference 2. The approach contains four steps:

- Assess equipment survivability
- Specify network topology
- Specify fallout radiation levels over network equipment locations
- Characterize network performance.

The first, and most difficult step, and the focus of this report, assesses the effects of fallout radiation on network telecommunications equipment. In the absence of detailed

1-2

analyses, where circuit diagrams might be employed, the first step seeks to optimize the available data through analytic equipment survivability modeling. Step two identifies the topology of the network under investigation. The third step uses a radiation dispersion model to specify radiation dosage levels at particular network equipment. Based on data obtained in steps one through three, the last step models and simulates the connectivity of a radiation-exposed network. Approaches for accomplishing Steps 2-4 have been identified in Reference 1 and will therefore not be addressed in detail hereinafter.

Assessing the effects of fallout radiation on telecommunication resources is critical to understanding the nation's telecommunication capabilities in the event of a nuclear war. The key to addressing this issue is understanding equipment level radiation effects. On the recommendations of the OMNCS document, <u>Fallout Radiation Effects on Telecommunication Networks: Analysis Methodology</u> (Reference 1), dated December 3, 1986, the following activities have been undertaken:

- Analyze existing radiation piece-part data to characterize the probability of survival for the various technologies.

- Assess equipment performance using the established construct presented in Reference 1 and described in section 2.1 of this report.

- Apply bounding techniques that will provide sufficient statistical confidence levels of equipment performance.

The methods described in Reference 1 provide statistically valid conclusions with sufficient confidence to be useful to the OMNCS and the telecommunications community.

1.2 PURPOSE

This report proposes the OMNCS' most comprehensive method, to date, for assessing the effects of fallout radiation on telecommunication network elements. In particular, this report demonstrates how the results of radiation tests conducted on equipment piece-parts are integrated to support predictions of equipment survivability. Further, this report evaluates a method for estimating network switching equipment survivability based on the piece-part survivability test data as a function of fallout radiation. It is noteworthy that the statistical confidence of the survivability estimates presented in this report are dictated by the limitations of the available piece-part data.

In addition, the method presented supports quantitative analyses that specify which telecommunications equipment, components, or piece-parts should be tested and/or analyzed for radiation susceptibility. This method also enables the OMNCS to locate the point of diminishing returns, where additional testing would provide little additional insight into predicting the connectivity of networks exposed to fallout radiation.

This investigation has three main objectives:

- Extend prior work on network performance characterization through the development and demonstration of the radiation effects methodology postulated in Reference 1, using the available data collected under the 5ESS Radiation Hardness Assessment Program (RHAP), Reference 3 and Reference 4.

- Develop an improved understanding of the fallout radiation testing needs of the OMNCS and determine the sensitivity of results with variations in test data distribution.

- Determine the additional OMNCS activities required to characterize the performance of the telecommunications infrastructure when subjected to a fallout radiation environment.

1.3 ASSUMPTIONS

A key ingredient to radiation equipment assessment is the availability of test data. Very few data exist that directly relate to the performance of telecommunications equipment of interest to the OMNCS. The primary obstacle in completing equipment assessments is a lack of data describing equipment performance as a function of fallout radiation. Few data exist largely because fallout radiation tests are destructive, and it is not economically feasible to perform destructive tests on expensive telecommunications equipment. However, data are available that relate to the performance of electronic piece-parts and materials, such as NMOS piece-parts. Although obtained from a variety of test programs, the limited data available can be used in equipment survivability models for meeting OMNCS objectives.

The survivability techniques that are typically employed by the radiation effects community require strict control over the selection of components and equipment design. Access to the detailed circuit schematics of the equipment is also required. Because such information are unavailable to the OMNCS, which cannot exercise such control over commercial vendors, alter-native methods are required to assess equipment radiation effects. This investigation uses statistical methods and available piece-part test data to estimate the performance of equipment in a fallout radiation environment.

Available piece-part performance data may be extrapolated to estimate the effects of fallout radiation on a particular switch

or transmission facility. Statistical extrapolation techniques applied on the piece-part data support equipment survivability assessments. In conjunction with post-attack radiation dosage level models, the capability of estimating equipment performance as a function of variations in fallout radiation can be used to support network connectivity predictions.

Several caveats are offered to ensure that this investigation is interpreted in the proper context. The list below highlights some of the initial assumptions considered during this analysis:

- Data collected are random samples of the telecommunications component piece-part population.

- The effects of prompt radiation, which are the gamma rays and neutrons released immediately following detonation, are not addressed.

- Critical function and critical module breakdown of the systems of interest to the OMNCS may not be available.

- Classical methods typically used by the radiation effects community are not used by the OMNCS because these methods require an excessive expenditure of resources to predict survivability as a function of fallout radiation.

- The statistical confidence of the survival estimates presented in the report are dictated by the limitations of the available piece-part data.

The results obtained in this investigation were studied to test the following propositions related to the performance of

the NSEP telecommunications infrastructure in a fallout
radiation stressed environment:

- Fallout radiation could significantly affect the
  overall performance of PSN component resources.

- Additional radiation piece-part test data may be
  required to adequately assess all critical PSN
  telecommunications equipment.

- Judicious testing of selected piece-parts could
  significantly reduce the observed variance of equipment
  survivability results.

1.4 ORGANIZATION

This report contains five sections. Section 2.0 reviews the
network level approach. Each step is discussed individually
along with an explanation of how the four parts of the approach
are interrelated.

Section 3.0 presents the method of assessing equipment
performance based on available piece-part data. This section
qualifies confidence levels that can be related to the equipment
survivability results.

Section 4.0 addresses the available radiation piece-part
test data, identifying who has conducted the test programs,
along with the utility and shortcomings associated with the
available data, as viewed by the EMP Mitigation Program. This
section concludes with an evaluation of the fallout radiation
methodology using the piece-part data from the OMNCS sponsored
5ESS RHAP. The results represent switch survivability as a
function of fallout radiation test data.

Section 5.0 summarizes the major findings of this investigation. This section is concluded with suggestions for future study, including recommendations for further fallout radiation assessment efforts.

2.0 FALLOUT RADIATION NETWORK LEVEL APPROACH

This section reviews the approach, under development by the OMNCS, for estimating the effects of fallout radiation on the performance of telecommunication networks (Reference 2). As illustrated in Exhibit 2-1, the approach consists of four steps: effects of fallout radiation on telecommunications equipment, network topology data base, radiation dispersion model, and the Network Connectivity Analysis Model (NCAM). Along with network topology and radiation dispersion levels, these equipment radiation effects may be used by the OMNCS to characterize network performance.

EXHIBIT 2-1

Network Level Approach
to Fallout Radiation Effects Analysis

STEP 1:
Effects of Fallout Radiation
on Telecommunications
Equipment

STEP 2:
Network Topology Data Base

STEP 3:
Radiation Dispersion Model

STEP 4:
Network Connectivity Analysis Model

NETWORK PERFORMANCE ESTIMATIONS
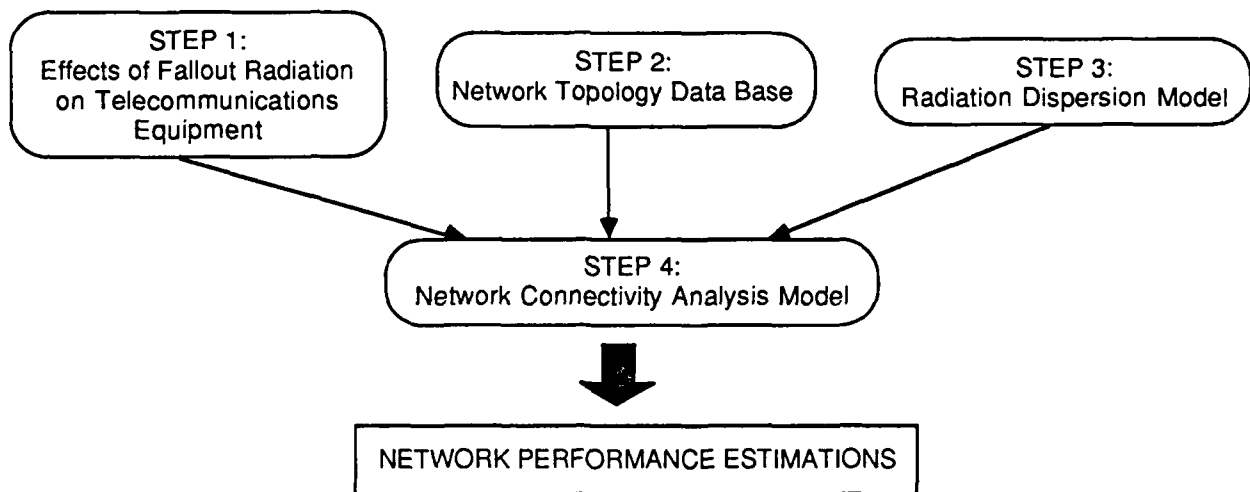
Fallout radiation is the residual radiation following detonation of a surface or near-surface nuclear burst (Reference 5). Wind and other associated weather conditions spread the fallout radiation to locations away from ground zero. This will inevitably include the locations occupied by NSEP telecommunications equipment. Almost all currently manufactured telecommunications equipment contain semiconductor devices, making unshielded communication systems susceptible to failure due to fallout radiation exposure. Even at low dosage levels, the effects of fallout radiation on semiconductor devices can be quite severe.

2.1 FALLOUT RADIATION EFFECTS ON TELECOMMUNICATIONS EQUIPMENT

Based on available data collected, equipment survivability relative to fallout radiation exposure can be assessed by implementing strategies similar to those applied in the EMP equipment survivability studies (Reference 6 and Reference 7). First, a unique survival probability distribution is calculated using the Bayesian Survivability Model (BSM) for each critical piece-part family. Second, the individual survival probability distributions of the piece-part families are combined to develop equipment survival probability distributions.

In accomplishing the first step, a variety of methods have been explored to evaluate the response of telecommunications equipment to fallout radiation. Before postulating any method, several ground rules are established related to the information available to the OMNCS about the PSN equipment under study and the assumptions that qualify this investigation. In sum, the OMNCS neither intends to develop hardened equipment, nor control the type of commercially manufactured devices that are used in the equipment required to support NSEP initiatives. Further, the OMNCS cannot typically obtain the electrical schematics used in modeling equipment behavior for several reasons, not the least of which is the proprietary nature of that data.

The OMNCS requires the most technically sound and cost-effective method to support decisions concerning fallout radiation on federal telecommunications performance. Characterizing the system response by testing each and every piece-part and simulating the system response may likely offer the best prediction of equipment performance. However, such a methodology, typically used by the radiation effects community, requires an excessive expenditure of resources to predict equipment survivability. The alternative method proposed in this report makes the best use of the limited, available data in a manner consistent with the goals and resource limitations of the OMNCS' EMP Mitigation Program.

In Reference 1, the OMNCS proposed a probabilistic method to assess the network level response to fallout radiation. The method divided the system into telecommunications equipment, critical functions, critical modules, and piece-part technologies. The survival probability of the telecommunications equipment results from the combined effects of the survival probability of each technology within each critical module within each critical function. The procedure assumed that all special technology categories, or families, were equally represented and critical for successful equipment operation.

For the investigation presented in this report, neither information about the critical functions, nor the critical modules of the 5ESS are available, as was requested in Reference 1. Therefore, the analysis of the fallout radiation response of the 5ESS is based solely on information related to the piece-part technology families. Piece-part technology families, such as bipolar linear, CMOS, TTL, and LSTTL, are used instead of specific commercial piece-parts, such as 2N2222, CD4000, 5400, and 54LS00, because information is more plentiful on the former set. Although the OMNCS does not control the selection of devices used in the equipment of interest to the OMNCS (e.g., the 5ESS), the

same piece-part technology families will likely be used in separate equipment (e.g., separate 5ESS switching systems). In accordance with the objectives of the OMNCS, this approach provides the ability to make general estimations on the survivability of each equipment type based on its piece-parts.

The estimation of the effects of fallout radiation on telecommunications equipment is addressed in detail in the following two sections. Section 3.0 shows the approach for developing equipment survival distribution curves based on piece-part data. Section 4.0 discusses the piece-part data used to develop the survival distribution curves, and presents the survival distribution curves.

2.2 NETWORK TOPOLOGY

The second step required for the network level analysis, as indicated in Exhibit 2-1, discusses the network topology. Available network data bases have been processed to specify switch types and locations, switch interconnections, transmission facility types and locations, physical network structure, and logical network structure. This results in a comprehensive specification of the network topology to be used for analyses addressing network performance as a function of fallout radiation levels.

2.3 RADIATION DISPERSION MODEL

In the third step, the Single Integrated Damage Assessment Capability (SIDAC) model predicts fallout radiation levels over geographic locations. SIDAC is a DoD-approved model currently used by the Joint Data Systems Support Center (JDSSC). The attack scenarios used as input to SIDAC describe, for example, weapon locations, heights of burst, wind currents, and prompt gamma radiation yields. SIDAC outputs the radiation dosage levels over continental United States. The dosage levels to

which the PSN equipment are exposed are determined by knowing the locations of the network equipment and the dosage levels over geographic locations. This information is necessary for selecting the dosage-dependent survival probability distributions appropriate for each network switch and transmission facility.

## 2.4 NETWORK CONNECTIVITY ANALYSIS MODEL (NCAM)

In the fourth step, the performance of the network after exposure to fallout radiation is characterized using the NCAM. The approach is similar to the one employed in the network level EMP analyses (Reference 6). In this application, the NCAM uses, as input data, the survivability of the equipment to fallout radiation, the network topology, and the radiation dosage level to which the network equipment are exposed. Simulated exposure of the network to radiation is replicated many times via a Monte Carlo process. This results in the calculation of the mean and standard deviation of the point-pair connectivity metric of all the simulations. This metric is calculated from both a physical and logical connectivity perspective. Completion of these simulations allows the OMNCS to quantitatively estimate the effects of fallout radiation on network performance. As more test data become available to assess the fallout radiation effects on the network equipment, the accuracy and reliability of the network level results will be enhanced.

3.0 EQUIPMENT RADIATION EFFECTS METHODOLOGY

This section describes the method applied to estimate the survival probabilities of telecommunications network elements as a function of fallout radiation. Using the results of radiation piece-part data for each technology family, a series of Cumulative Distribution Function (CDF) and Probability Density Function (PDF) curves are developed that describe the technology family survivability against fallout radiation. A separate curve is developed for each range of radiation dosage levels to which telecommunications equipment are exposed. Based on readily available test data from electronic component radiation hardness testing programs and knowledge of component technologies, this method affords network-wide characterization of equipment performance as a function of fallout radiation.

Exhibit 3-1 shows the method for estimating the survivability of telecommunications equipment, exposed to fallout radiation, to support network level connectivity studies.

EXHIBIT 3-1

Equipment Survival Probability Methodology

3-1
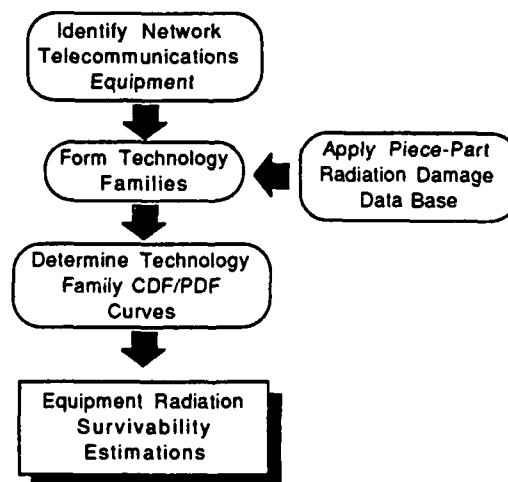
It is noteworthy that only equipment failure due to radiation effects on the physical components of equipment hardware are examined. The effects of radiation on the proper functioning of controller software or telephone company maintenance personnel are not considered, although such effects could impact telecommunications equipment performance.

3.1 TESTING VERSUS ANALYSIS

As first presented in Reference 1, the response of network equipment to fallout radiation can be evaluated using either radiation testing or analytic techniques on equipment piece-parts. Within the given initial conditions that bound this study, the major findings suggest that the proposed analytical techniques for estimating network element performance, in conditions of stress, provide an appreciable cost/benefit advantage over exhaustive experimental testing.

Assessing the system functional response to variations in fallout radiation is typically accomplished by testing all individual piece-parts in laboratory radiation test facilities and analyzing the circuit performance. However, test data on much of the equipment of interest to the OMNCS are not available. Although it is recognized that additional radiation piece-part test data may be required to adequately assess all critical PSN telecommunications equipment, extensive testing is costly and would likely produce results that maintain a high degree of uncertainty. The cost is attributed to the large number of samples that require testing. The uncertainty results because the OMNCS has neither full control over the testing procedures, nor the devices used in the telecommunications equipment. To fulfill the objectives of the OMNCS, probabilistically assessing the equipment radiation response is more cost-effective than deterministically assessing the radiation response.

3.2 EQUIPMENT TECHNOLOGY AGGREGATION

The first step in determining the fallout radiation response of the 5ESS is grouping the piece-part radiation data into technology families. For a variety of families, piece-part technologies are combined based on similar radiation response characteristics and similar device constructions. For example, in the 5ESS RHAP report (Reference 3 and Reference 4), each family of piece-parts is assumed to exhibit a uniform output response as a function of fallout radiation. Technology families are formed primarily for three reasons:

- Given a limited data set, aggregating piece-parts into families increases the confidence in the resulting probability of survival estimates.

- Given a comprehensive data set (test data on every piece-part), forming piece-part families streamlines data processing and computation.

- Given those cases where the inherent variations are small relative to the experimental and interpretation variations, introduced in Reference 1, combining families is statistically viable.

Combining piece-part families with small sample sets and similar distributions into technology families decreases the variance in these probability estimates. Note that combining piece-parts with large (>200) sample sets does not reduce the variance as dramatically.

3.2.1 Technology Families

Several technology families exhibit similar radiation responses, which gives rise to further technology family

3-3

combinations. A review of the 5ESS RHAP families shows that the piece-part technology families could be further categorized to reduce the number of families. Fewer families decrease the intrinsic statistical error of the BSM results that are perpetuated during the computation of the overall equipment survivability (Reference 8). In many cases, experimental and interpretation variations in the piece-part data, described below, influence the distribution curves of some families in such a way that some distributions appear very similar. Notice that not all piece-part families with similar distributions are grouped; it is recognized that some vastly different technologies might exhibit coincidentally similar distributions due to a limited amount of data points. In other words, although CMOS and Bipolar piece-part families may exhibit similar distributions, given a limited set of test data, the families are not combined. Regrouped piece-part families exhibit similar fallout radiation response distributions and are technically similar.

3.2.1.1 <u>Variations in Piece-Part Data</u>. Three types of variations in the piece-part response to radiation are briefly discussed below: inherent, experimental, and interpretation. Inherent variations result from the intrinsic properties of a piece-part; while experimental variations result from test conditions and procedures. Interpretation variations are based on the subjective judgements of the system users and designers. If inherent variations are small compared to the experimental and interpretation variations, combining families is statistically viable.

Inherent variations in the radiation response of piece-parts can result from differences between lots and vendors. In commercial piece-parts, lot-to-lot variations are produced by the differences in the processing parameters during the fabrication of a piece-part. Although processing parameters are controlled closely enough to produce an electrically functioning

piece-part, they may not be controlled close enough to produce piece-parts that are uniformly sensitive to radiation. The restrictions on the electrical parameters of a piece-part may be met differently by different manufacturers, thereby allowing for different radiation responses from electrically similar piece-parts. Vendor-to-vendor variations describe the differences among the processing methods used by individual vendors to fabricate piece-parts. The radiation failure threshold of standard commercial piece-parts with inherent variations may be greater by more than an order of magnitude, which suggests that predicting the exact radiation failure threshold of a particular piece-part can be difficult.

Experimental variations include test data format, test data age, parameters tested, temperature of the radiation test environment, and radiation exposure (dose) rate. Further details on experimental variations are presented in Reference 1.

Interpretation variations in piece-part assessments affect test results based on test data acquired under various programs with independent goals and objectives. Typically, the manner in which data are reduced, the differences between manufacturer specifications and designer specifications, and the distinction between piece-part degradation and piece-part failure, contribute to interpretation variations.

After the new families are determined, new CDFs and PDFs are computed and are then compared to the previously calculated distribution curves of the RHAP families. This comparison seeks to identify any decrease in the standard deviation about the family survivabilities. Such a decrease in the standard deviation indicates an improved estimate of the piece-part family behavior. In contrast, an increase in the family standard deviation would indicate that the proposed categorization of piece-parts is not justified. The particular combination of

piece-part families is no longer considered when an increase in the standard deviation results.

3.3 EQUIPMENT SURVIVAL PROBABILITY ESTIMATION

Once the technologies used in the switch have been identified and grouped into families, a method is required to estimate the effect of piece-part technologies performance on the overall performance of the switch. This method assumes that all technology families are equally represented in the switch and that the performance of each technology used in the switch is critical to the successful switch operation. If detailed information becomes available indicating that a particular technology used is not critical to the performance of the switch, then that technology is no longer considered in estimating radiation effects.

The calculation of estimated technology survival probability is based on a Bayesian statistical interpretation of component radiation hardness test data. The BSM is used to develop density and distribution curves that estimate technology survivability. The inputs to the model are fallout radiation test data and a noninformative prior distribution. The BSM is described in the OMNCS Bayesian Failure Probability Model Sensitivity Study report, dated May 30, 1986 (Reference 8).

In sum, available piece-part data are used to model the radiation response of each technology family. The estimated survivability of the network equipment (e.g., 5ESS switch) is then calculated as the convolution of estimated survival probabilities of each different technology family. Assuming that all piece-parts perform a necessary function, it must also be noted that the initial conclusions generated by this methodology are subject to change because all the piece-parts have not been tested.

4.0 FALLOUT RADIATION METHODOLOGY APPLICATION

This section shows quantitatively the strengths of the proposed methodology and its utility, given limited available piece-part fallout radiation survivability data. First, the origin of the radiation test data used in this application is examined. Second, an application of the methodology using the available data is presented. The results of this analysis show the advantages of the methodology even in situations where data are limited. Finally, by hypothetically increasing the sample size of the available data and thereby decreasing the variance of the results, this section shows improved overall switch survivability predictions.

4.1 PIECE-PART FALLOUT RADIATION TEST DATA

The piece-part fallout radiation test data used in this investigation were collected from the following sources in the radiation community, under various programs with independent goals and objectives:

- U.S. Army Harry Diamond Laboratories (HDL) Component Response Information Center (CRIC)

- Defense Atomic Support Agency Information Analysis Center (DASIAC) Electronics Radiation Response Information Center (ERRIC)

- NASA Jet Propulsion Laboratory

- Institute for Electrical and Electronics Engineers (IEEE) Transactions on Nuclear Science.

4-1

The data used in this application were collected under the 5ESS
RHAP (Reference 3 and Reference 4) and reflect actual fallout
radiation test results.

4.2 5ESS APPLICATION

Fifty-two piece-part families are identified in the 5ESS
RHAP final report. The twenty-nine families with data are listed
in Exhibit 4-1, including the number of piece-parts in the
sample; no data are identified for the remaining twenty-three
families defined under the RHAP. Piece-parts of the same tech-
nology family, are assumed to exhibit similar radiation response
distributions. Due to the lack of information on some piece-
arts, the sample size is assumed to be one in cases where the
data base does not indicate a sample size.

The data presented in Exhibit 4-1 are used as inputs for the
BSM described in Reference 8. For this investigation, the eight
"bins" below describe radiation dosage levels to which the equip-
ment and its piece-parts are exposed:

> 0-500 Rads(Si)
> 500-1k Rads(Si)
> 1k-5k Rads(Si)
> 5k-10k Rads(Si)
> 10k-20k Rads(Si)
> 20k-30k Rads(Si)
> 30k-40k Rads(Si)
> 40k-50k Rads(Si).

One Rad(Si) equals 10^{-5} joules of energy absorbed in 1 gram of
silicon mass. These bins have been created arbitrarily, but
with an eye towards ensuring that the failures of the piece-part
technology families are detected. Within each bin (e.g., 500-1k
Rads(Si)), the piece-part technology family survival probabili-
ty, described by its Bayesian posterior survival probability

Exhibit 4-1
Initial Technology Families

Piece-Part Family	Sample Size
Diode	6
Bipolar Transistor	28
Bipolar Digital - ALSTTL	36
Bipolar Digital - ECL	6
Bipolar Digital - FTTL	89
Bipolar Digital - IMOX	6
Bipolar Digital - LSTTL	163
Bipolar Digital - OXIL	13
Bipolar Digital - STTL	18
Bipolar Digital - TTL	6
Bipolar Linear - CBIC	1
Bipolar Linear - Driver/Receiver	17
Bipolar Linear - Op-Amp	37
Bipolar Linear - Timer	6
Bipolar Linear - Voltage Regulator	6
CMOS Linear - A/D Converter	5
CMOS Linear - Switch/Mux	29
CMOS Digital - 4k/16k SRAM	119
CMOS Digital - CD4000	59
CMOS Digital - 54HC	24
CMOS Digital - CHMOS II	26
NMOS Digital - AT&T NMOS	1
NMOS Digital - 8k/16k SRAM	14
NMOS Digital - 4k SRAM	17
NMOS Digital - DRAM	40
NMOS Digital - HMOS I	182
NMOS Digital - HMOS II	48
NMOS Digital - Misc.	38
NMOS Digital - UVEPROM	118

distribution, is estimated using the BSM. As a result, each piece-part technology family has eight survival distribution curves corresponding to the eight fallout radiation dosage level bins.

Exhibit 4-2 and 4-3 are examples of the CDF and PDF curves generated using the data in Exhibit 4-1. The curves represent the survivability distributions of the two technology families, CMOS Digital 4k/16k SRAM and the CD4000. These distributions are calculated using the BSM and represent the survivability of technologies when exposed to a radiation dosage level between 500-1k Rads(Si). The mean and standard deviation of the PDFs may be calculated for each of the families to provide an average survivability and a measure of the survivability variation within a technology family.

Exhibit 4-2(a)
CDF Survival Curve for 4k/16k SRAM, 500-1k Rads(Si) Bin
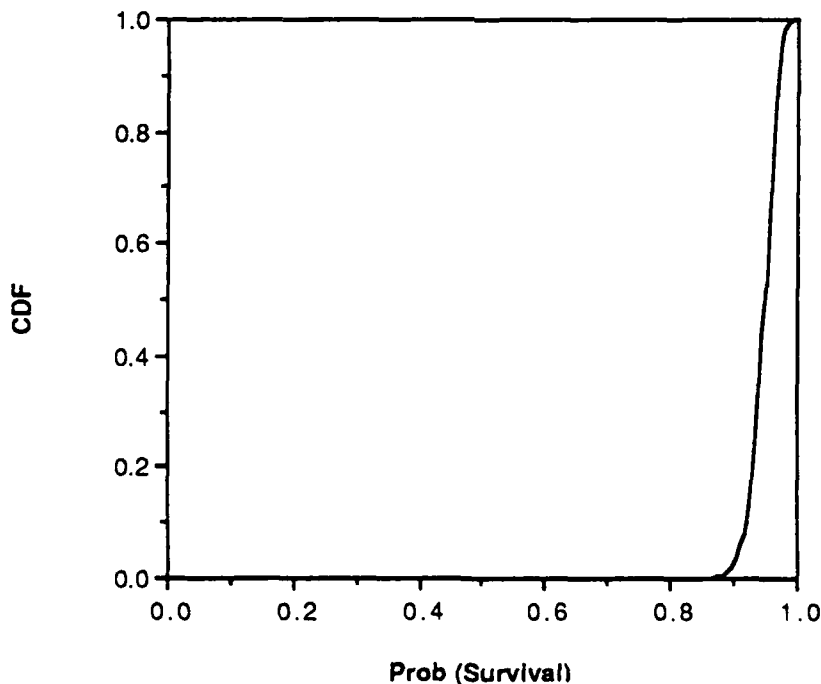(113 survivals out of 119 samples)

4-4

Exhibit 4-2(b)

PDF Survival Curve for 4k/16k SRAM, 500-1k Rads(Si) Bin
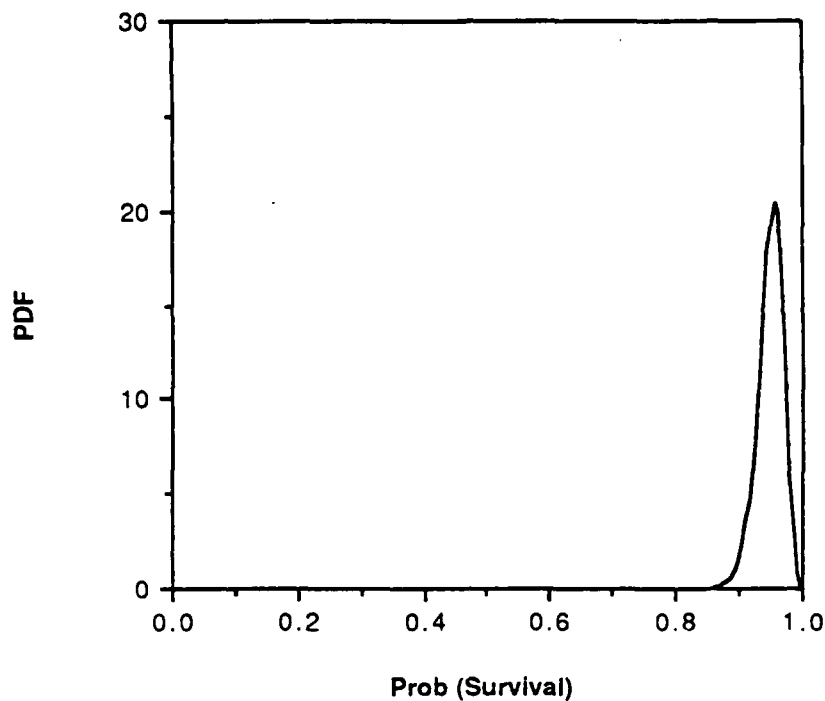
(57 survivals out of 59 samples)

EXHIBIT 4-3(a)

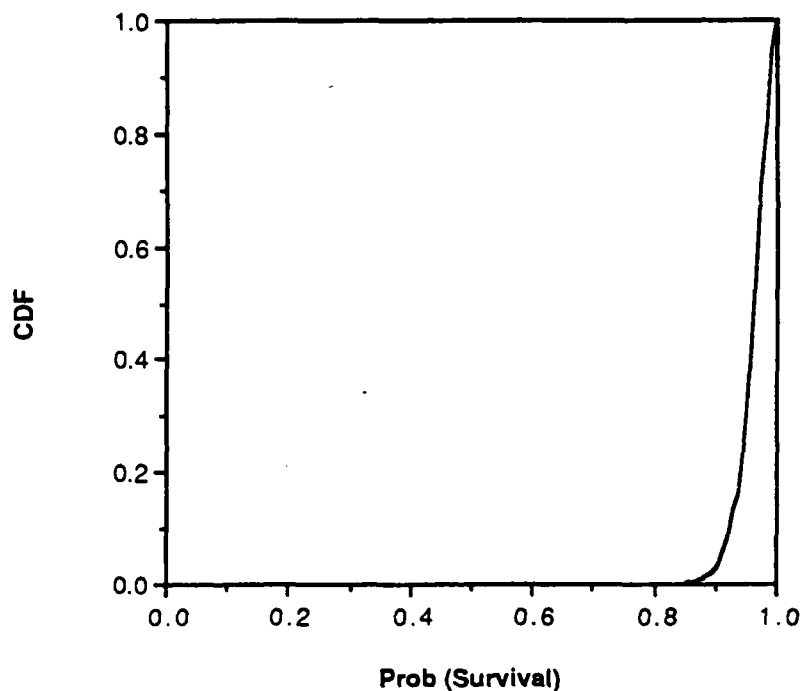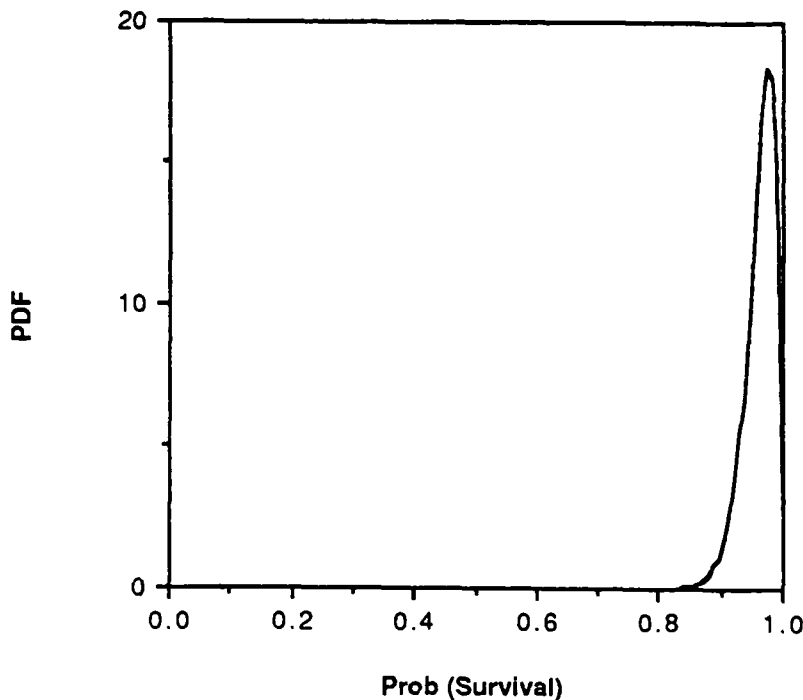CDF Survival Curve for CD4000, 500-1k Rads(Si) Bin

EXHIBIT 4-3(b)

PDF Survival Curve for CD4000, 500-1k Rads(Si) Bin

4.2.1 New Technology Families

As explained in section 3.2, some of the families described in Reference 3 and listed in Exhibit 4-1 are regrouped. The new families exhibit the following characteristics:

- Selection of families to be combined is based on limited available test data.

- Piece-part families for which all samples survive a total dose greater than 50k Rads(Si) are assigned a survival probability of one.

Fifteen piece-part technology families, reduced from twenty-nine, are listed in Exhibit 4-4, including the sample size for each family. Recognize that additional data may require that a different set of families be formed.

Exhibit 4-4
New Technology Families

| Piece-Part Family	Sample Size
Bipolar Digital - ALSTTL	36
Bipolar Digital - FTTL	89
Bipolar Digital - IMOX	6
Bipolar Digital - LSTTL	163
Bipolar Digital - OXIL	13
Bipolar Linear - Driver/Receiver, CBIC	18
Bipolar Linear - Op-Amp, Timer, Voltage Regulator	49
CMOS Linear - A/D Converter, Analog Switch/MUX	34
CMOS Digital - 4k/16k SRAM	119
CMOS Digital - CD4000	59
CMOS Digital - 54HC	24
CMOS Digital - CHMOS II	26
NMOS Digital - AT&T NMOS	1
NMOS Digital - 8k/16k SRAM, 4k SRAM, DRAM, UVEPROM, Misc. NMOS	227
NMOS Digital - HMOS I, HMOS II	230

After regrouping technology families, CDF and PDF curves, along with the PDF standard deviation are computed for each family. These new standard deviations are then compared to the standard deviation generated from the RHAP families as described in section 4.2. Combining technology families with similar distributions decreases the standard deviation of the PDF curve. Likewise, combining technology families with dissimilar distributions increases the standard deviation of the PDF curve.

This report assumes that a 10 percent decrease in the standard deviation indicates that distributions are sufficiently similar to warrant forming families. For example, Exhibit 4-5 includes the PDF curves for two technically similar piece-part families and their combination as defined in Exhibit 4-1 and Exhibit 4-4: HMOS I, HMOS II, and HMOS I&II. The standard deviation for HMOS I equals .0359 and for HMOS II equals .0647. The standard deviation of the new group equals .0317. That is, by combining these technology families the new standard deviation for the combined family is reduced.

A shortfall of forming families may result when combining large data populations with small populations. Regardless of the small population data set, when combined with very large data set, the small population may be overwhelmed by the affect of the larger population. Moreover, the small and large population combination may exhibit a reduced standard deviation because of the increased sample size. Therefore, technology families should only be combined if it is technically and statistically defensible (section 3.2.1).

An alternative method for determining if piece-part technologies are sufficiently similar to justify forming families may be based on multivariate statistical analysis methods. Multivariate analyses may be used to rigorously evaluate the

4-8

Exhibit 4-5
Combining Similar Technology Families:
HMOS I & II Families
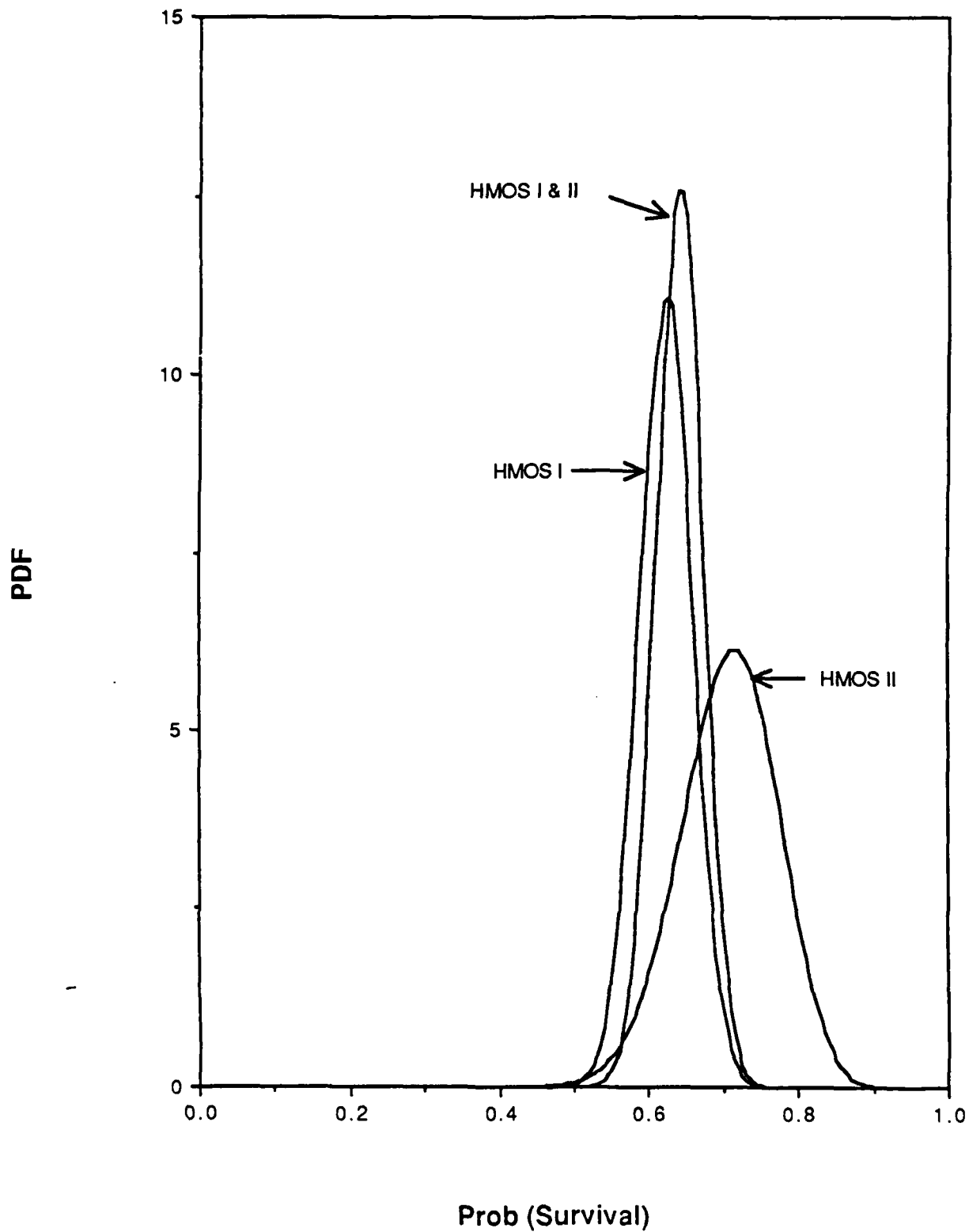
similarity between two piece-part technology data (Reference 10 and Reference 11). Although beyond the scope of this investigation, multivariate statistical analysis methods are recommended for further study.

4.2.2 Switch Survivability Estimation

As in Reference 3, this method assumes that all technology families are equally represented and critical for successful equipment operation; all of the technology families must survive for the switch to survive. The survival probability for the switch is equal to the product of the survival probabilities of each piece-part technology. After the CDF curves of the piece-art families defined in Exhibit 4-4 are generated, the switch survivability is calculated. A random value between zero and one is generated that describes a CDF ordinate value (y-value) for each piece-part technology family. The corresponding CDF abscissa value (x-value) equals the piece-part technology family survival probability. In this manner, the survival probability is calculated for each piece-part technology family. The 5ESS switch survivability is calculated using the Monte Carlo procedure.

Although the CDF is a complete description of the technology family survival probability, it is not the most ideal form for illustrating piece-part or equipment survivability. For these, the PDF curve is generated by sorting each calculated survival probability from the Monte Carlo procedure into .01 intervals from 0 to 1. The PDF curves estimating the 5ESS switch survivability are shown in Exhibits 4-6, 4-7, and 4-8. These equipment level survivability curves are based on the survivability distribution of the piece-part families which comprise the equipment.

As shown in Exhibit 4-6, the effects of fallout radiation are small at low dosage levels, which results in a high switch survivability estimation.

Exhibit 4-6

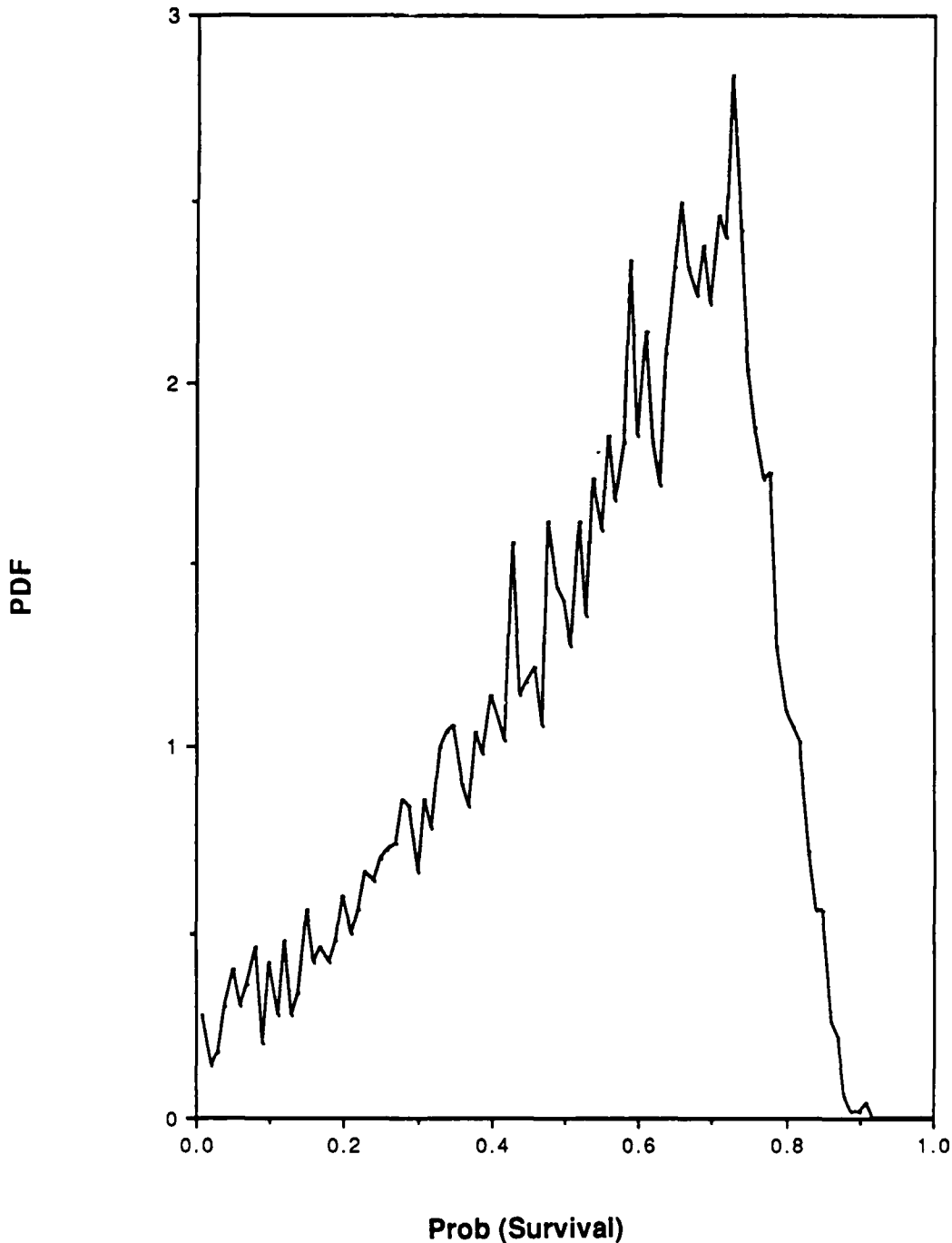PDF Survival Curve for the 5ESS Switch, 0-500 Rads(Si) Bin
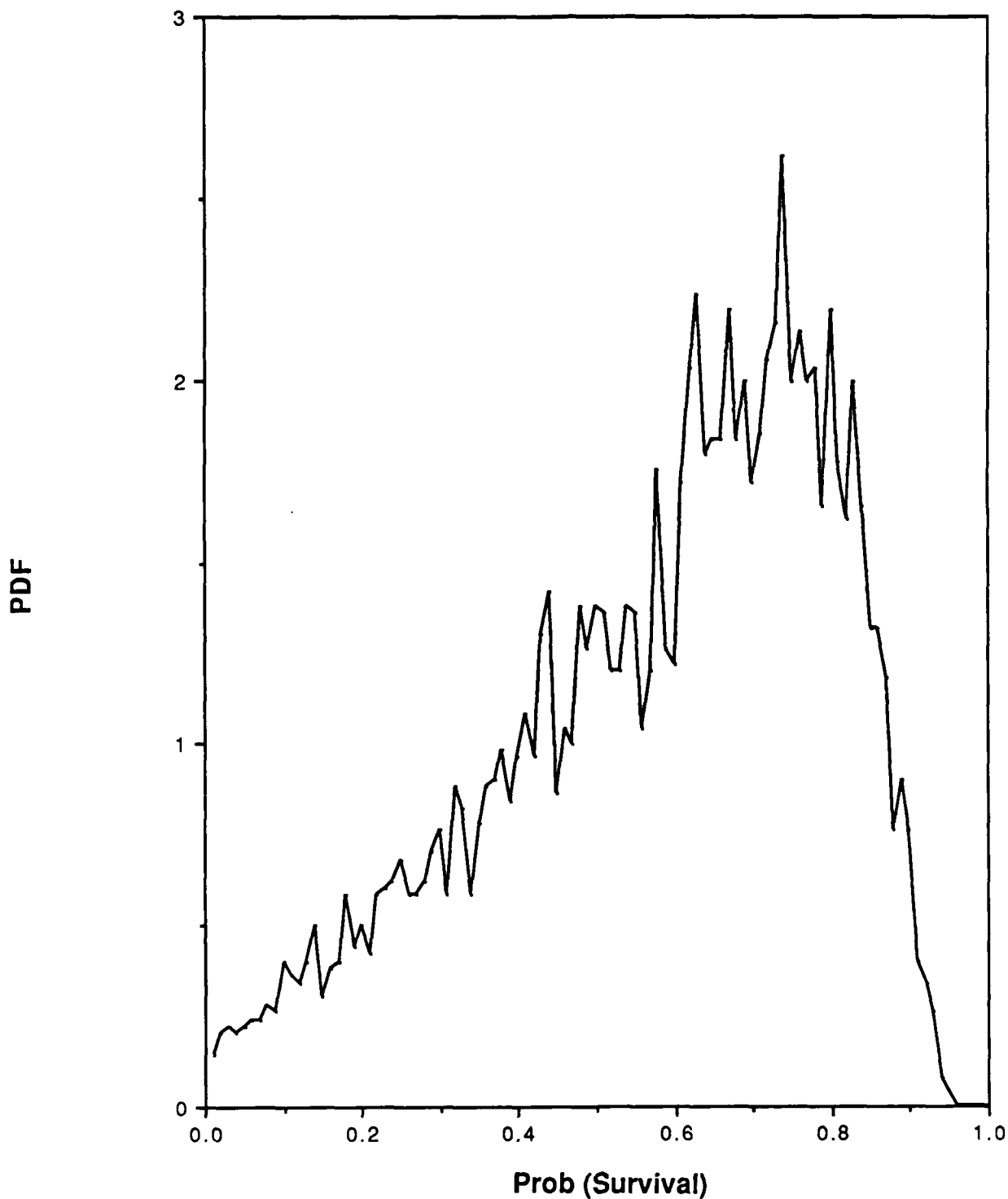
A characteristic of the Monte Carlo procedure is that the number of runs determines the "smoothness' of the curve. A wide variance, resulting from a small sample size (only a single test data point), increases the jaggedness of the curve, as shown in Exhibit 4-7.
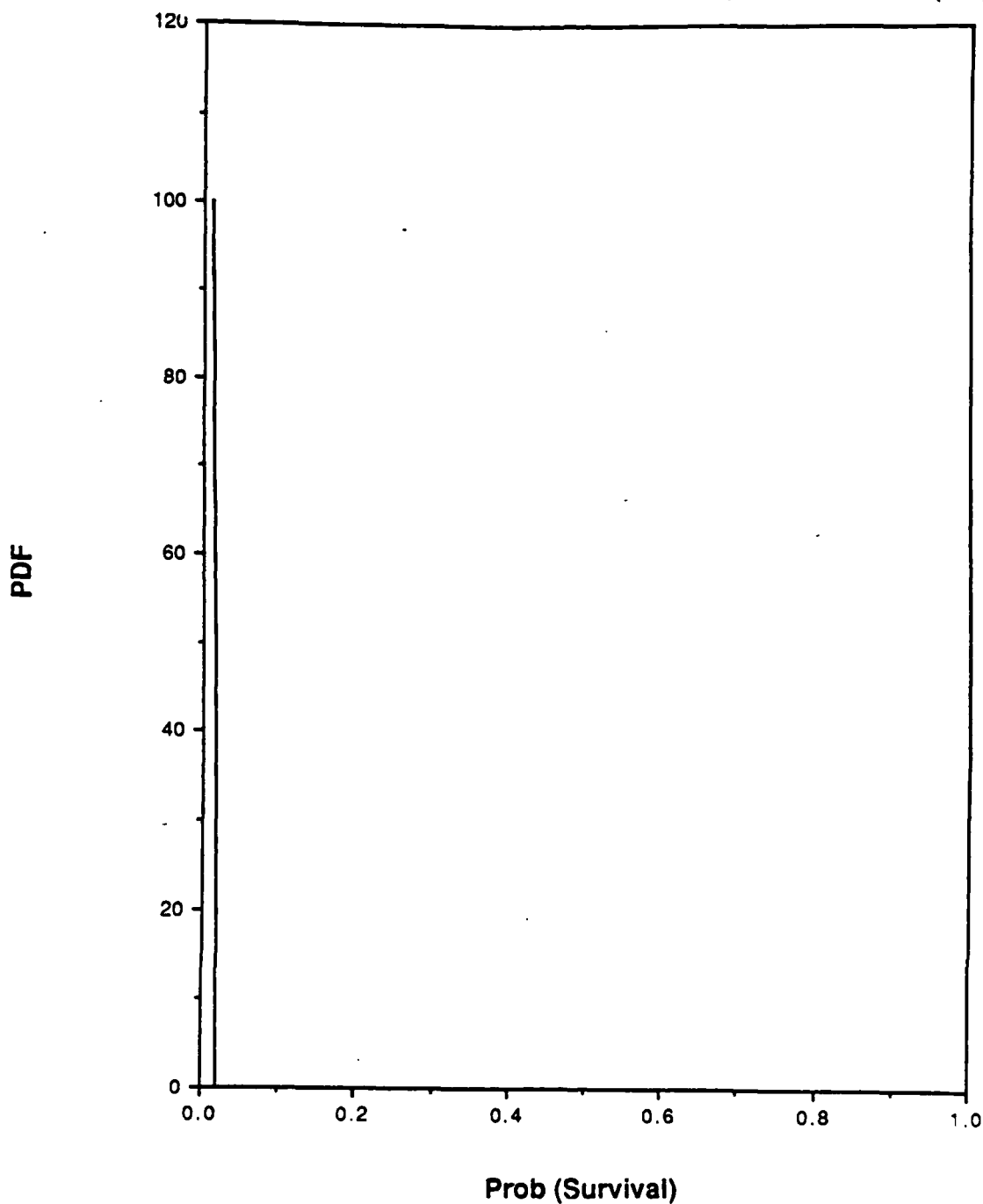
Exhibit 4-7
PDF Survival Curve for the 5ESS Switch, 500-1k Rads(Si) Bin

Prob (Survival)

In Exhibit 4-8, the switch survivability decreases rapidly in the 1k-5k Rads(Si) bin because all test data on piece-parts in the HMOS piece-part family fail in this bin.

Exhibit 4-8
PDF Survival Curve for the 5ESS Switch, 1k-5k Rads(Si) Bin

PDF

Prob (Survival)

4.3 EFFECTS OF INCREASED TEST DATA SAMPLE SIZE

The limited test data sample size applied in section 4.2 decreases the accuracy of the survivability predictions for the piece-part technologies and further decreases the accuracy of the switch survivability predictions. This section examines the effects of increasing the sample size relative to the following topics:

- Piece-part technology survivability
- Mean switch survivability
- Switch survivability approximation
- Switch survivability given a piece-part technology with only one data point.

Major findings of this investigation, shown in Exhibit 4-9 through 4-11, indicate that increasing the sample size reduces the variance of the predicted piece-part survivability and switch survivability.

Exhibit 4-9 is the PDF curve for the CMOS 54HC technology family in the 10k-20k Rads(Si) bin and shows graphically how increasing the sample size reduces the standard deviation of the predicted survival probability. The graph is generated by hypothetically increasing the sample size by a factor of 2, 5, 10, and 20, while also increasing the number of survivals by the same proportions. By reducing the variance of the technology family distribution, the accuracy of the equipment survivability estimates are increased.

Exhibit 4-10 plots the standard deviations of the PDF curves in Exhibit 4-9. Exhibit 4-10 indicates that the standard deviations decrease rapidly with an increase in sample size. For example, based on 200 survivals out of 200 samples, the mean survival probability is greater than 0.999. Thus, markedly

4-14

Exhibit 4-9
Effects of Increased Sample Size on the
PDF Survival Curves, 54HC Family

Sample Size = 480

Sample Size = 240

Sample Size = 120

Sample Size = 48

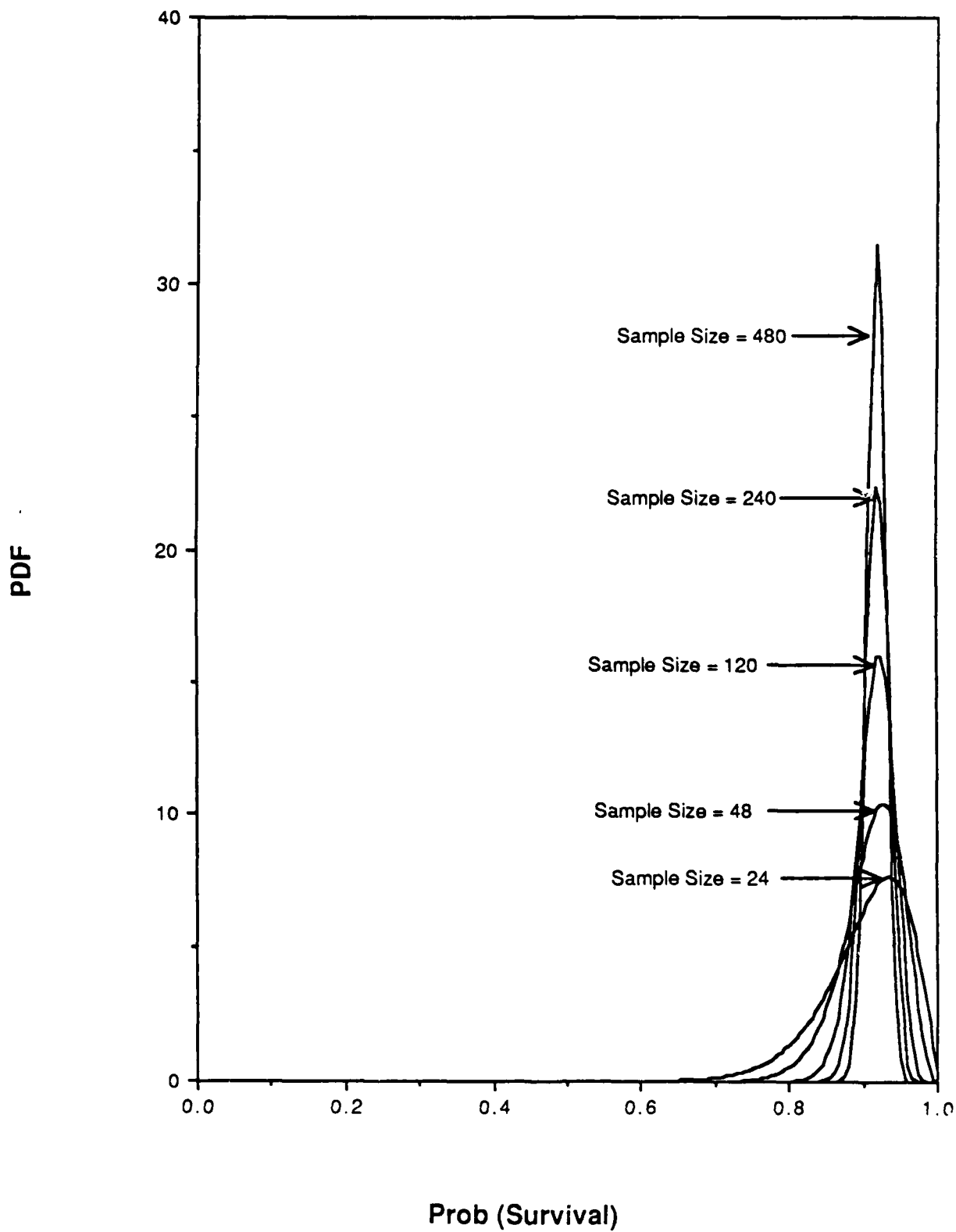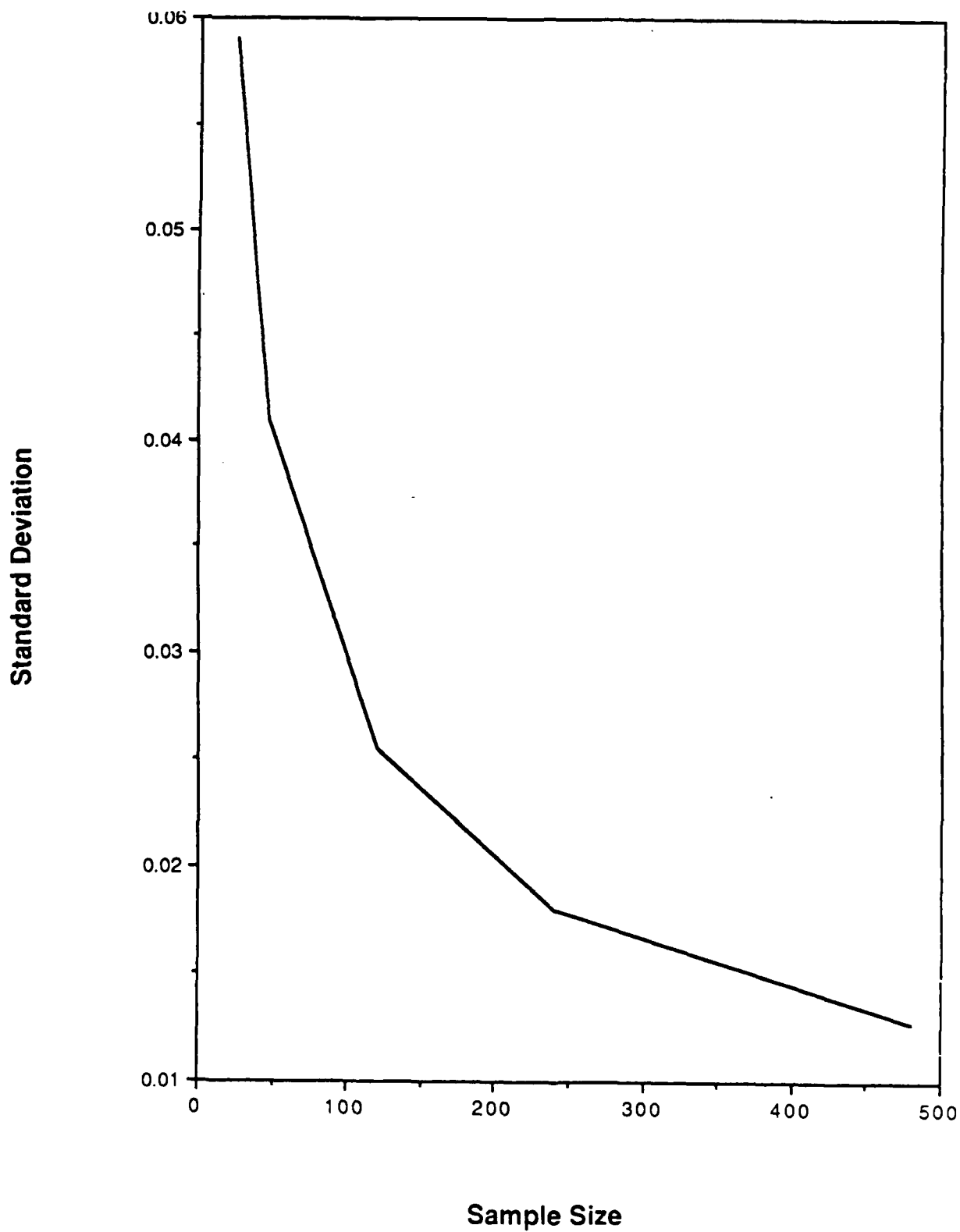Sample Size = 24

Prob (Survival)

4-15

Exhibit 4-10
Standard Deviation vs. Sample Size of
54HC Family PDF Survival Curves

improved results may be obtained by increasing the sample size to approximately 200 samples, which is an attainable number of data points.

Exhibit 4-11 shows the effects of an increased sample size on the mean survivability of the 5ESS switch. The solid diamonds depict the 5ESS survival probability determined from the actual (initial) sample sizes. The open squares depict the 5ESS survival probability determined by increasing the sample size of each technology family to approximately 200, while maintaining the same survival to sample size ratio. For all three bins, increasing the sample size increases the survival probability and reduces the standard deviation of the switch.

Exhibit 4-12 shows the effects of an increased sample size on switch survivability approximations. Exhibit 4-12 is the switch survivability in the 500-1k Rads(Si) bin. In this bin, only the SRAM and the CD4000 technology families exhibit any failures. The curve labeled "SRAM & CD4000" represents the switch survivability using only these two families. The curve labeled "SRAM, CD4000 & Others" represents the switch surviva-bility given that the SRAM and CD4000 families maintain their initial sample size and all other technologies exhibit an in-creased sample size. As expected, Exhibit 4-12 shows that if all other families both survive and have increased sample sizes (200 samples), the predicted switch survivability from this methodology converges towards the switch survivability of the "SRAM & CD4000" curve. Exhibit 4-12 indicates that for any given bin, the switch survivability depends primarily on the piece-part technologies that exhibit some failures.

Exhibit 4-13 illustrates the significance of obtaining addi-tional radiation data for specific technology families, which presently contain insufficient sample sizes. For example, the NMOS piece-part family has only a sample size of one. If the

Exhibit 4-11
Effect of Increased Sample Size on the
5ESS Switch Mean Survival Probability
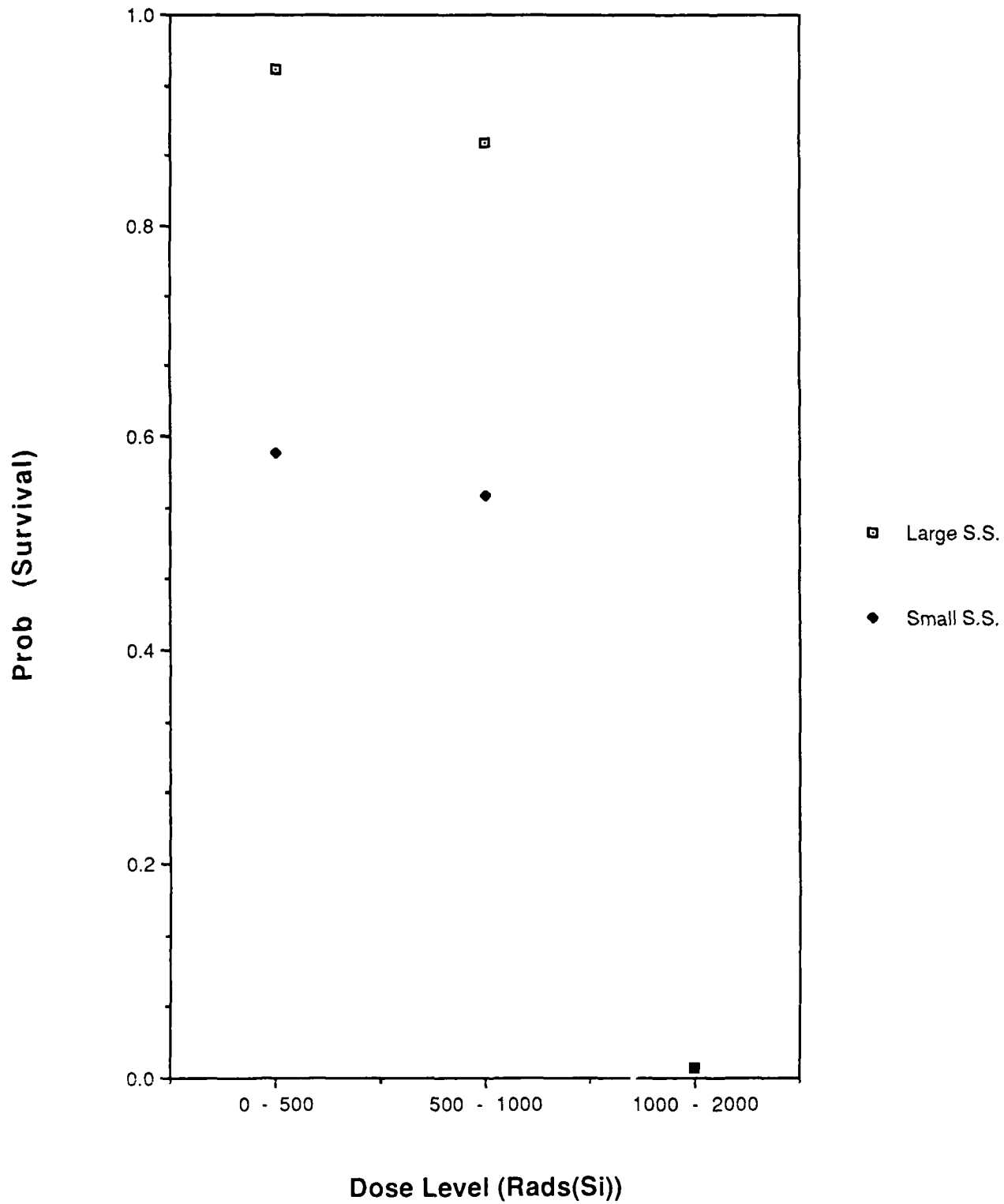
Exhibit 4-12
Effect of Increased Sample Size on
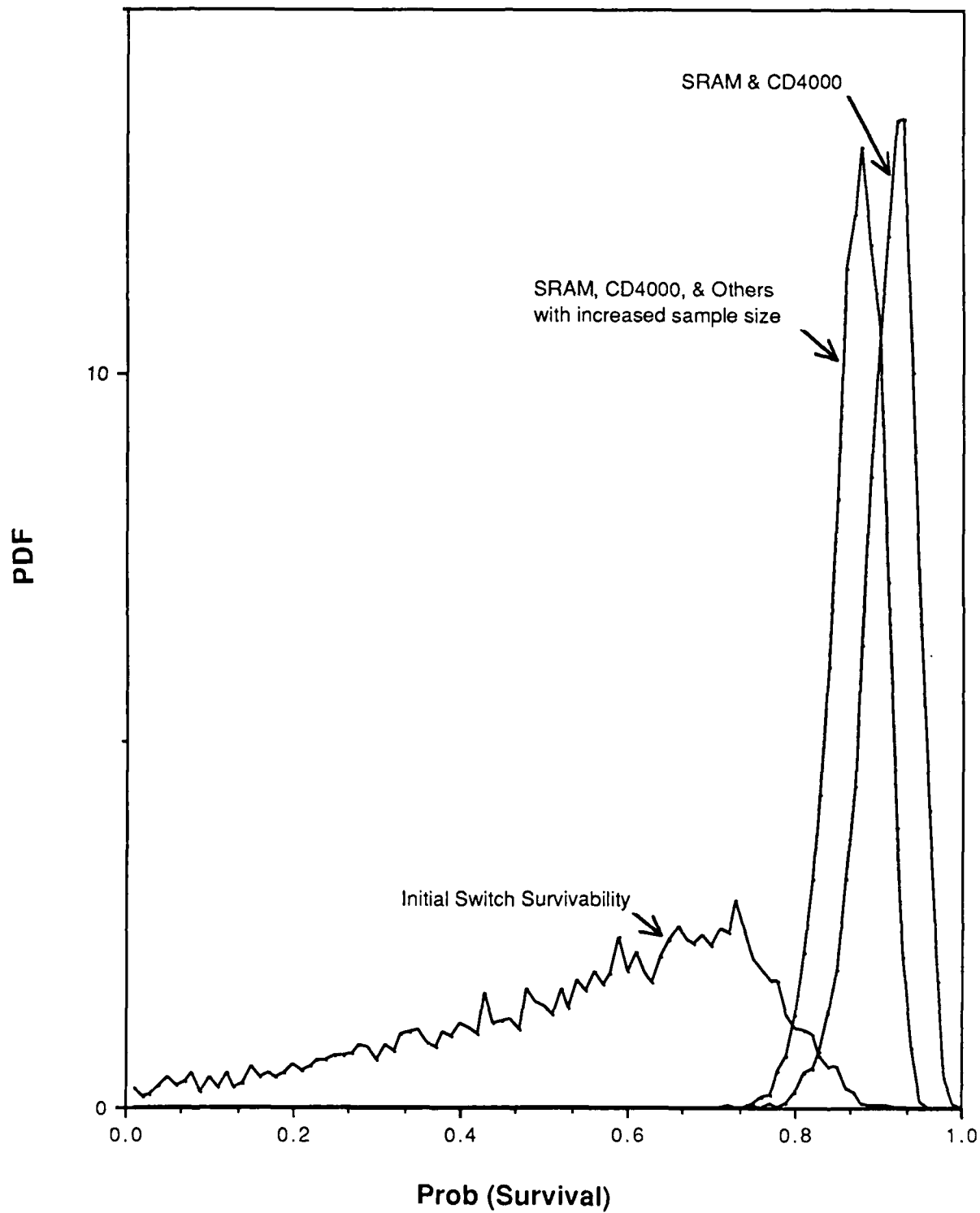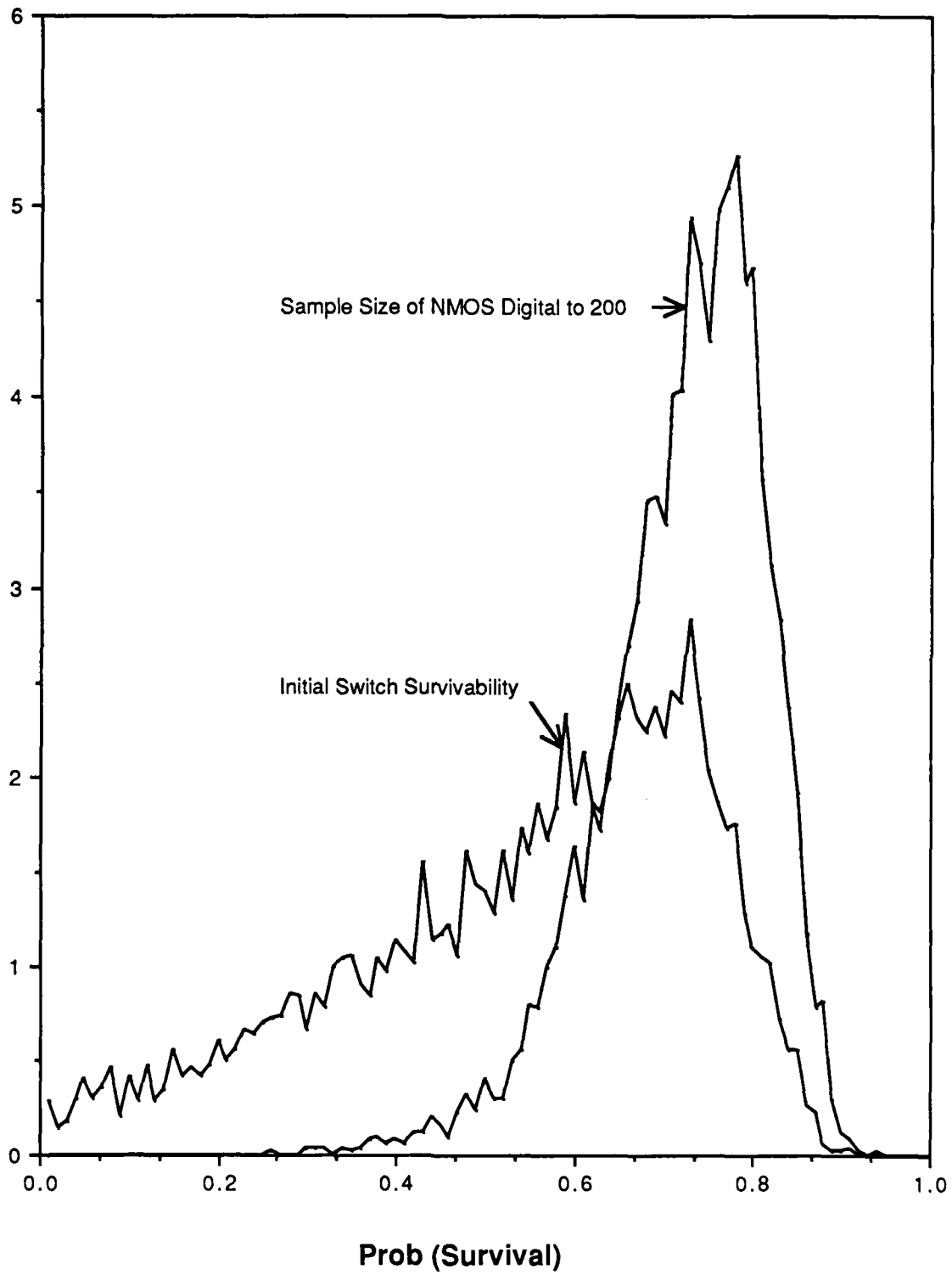**Estimated 5ESS Switch Survivability**

Exhibit 4-13
Effect of Increased Sample Size of NMOS Family
(Small Sample Size) on the 5ESS Switch Survivability

Sample Size of NMOS Digital to 200 →

Initial Switch Survivability ↘

PDF

Prob (Survival)

sample size were increased to 200 and the number of survivals remained proportional, the standard deviation of the new switch survivability is significantly reduced relative to the that of the initial switch survivability.

In summary, this section applied the proposed methodology, presented the strengths and limitations of the methodology, and illustrated the results. Overall, the results indicate that, given limited available data, telecommunications equipment performance _can_ be sufficiently characterized to provide a basis for network level connectivity analyses. Further, it was shown that by collecting more piece-part test data, markedly improved equipment level fallout radiation assessments can be obtained.

5.0 SUMMARY

In this work, the EMP Mitigation Program evaluates a methodology for addressing the effects of nuclear weapon generated fallout radiation on telecommunication network assets. While earlier work set forth this methodology, this investigation applied actual vulnerability test results to predict equipment survival probability and can be used as a basis for further radiation effects assessments.

5.1 CONCLUSIONS

The primary conclusion of this work is that given limited available data, the proposed method can predict fallout radiation effects on network telecommunications equipment. This is important for applications in equipment performance and network performance modeling in simulated radiation environments. Along with enhanced radiation effects performance modeling, it is significant that the type and amount of test data necessary for qualitatively and quantitatively improved results can be identified to model equipment performance.

As shown in section 4.0, the effects of fallout radiation are small at low dosage levels (bin 1 and bin 2). More pronounced variations in equipment performance were exhibited for radiation dosage in the 1k-5k Rads(Si) bin. Finally, the results indicate that by increasing the sample size to approximately 200 samples, the statistical quality of survivability predictions can be significantly improved. Further, increasing the sample size of piece-part technologies with a small sample size may improve the degree of confidence in equipment survivability predictions.

5.2 RECOMMENDATIONS

Based on the positive results presented in this report, the OMNCS should continue the development of the modeling techniques and the expansion of the data bases required to support the radiation assessment methodology that has been presented. The future efforts should focus on the following areas:

- Continue the development of modeling techniques. The methodology presented establishes the framework for completing the network level assessments of radiation effects. Future efforts should focus on developing modeling techniques to enhance the accuracy and flexibility of the existing methodology. More statistically rigorous methods for combining technology families, such as multivariate statistical analysis methods (Reference 10 and Reference 11), should be evaluated for inclusion in the methodology. A first attempt at enhancing the approach is contained in Appendix A.

- Collect the available data to support radiation effects assessments. The data used in this effort were used because they had been collected under a previous program for the OMNCS. Much larger quantities of component data are readily available, and could be entered into a data base for the OMNCS to support the radiation effects assessments. The OMNCS should also continue to work with equipment vendors to identify those technologies that are used in the telecommunication assets that support NSEP initiatives.

- Develop guidelines for the collection of test data. While large quantities of data are readily available, it may be necessary for the OMNCS to support limited testing programs to provide critical data for some network assessments. As part of the development of

this methodology, the OMNCS should identify testing
requirements that are consistent with the goals and
objectives of this program. Such requirements would
include appropriate selection of devices to be tested
and appropriate sample sizes.

. <u>Prioritize system assessment efforts</u>. The OMNCS should
prioritize future telecommunications asset assessment
efforts to focus on those areas that will provide the
most information about network level effects. To
accomplish this, the OMNCS should perform sensitivity
analyses on the network level models to identify those
parameters that have the greatest impact on network
level results.

APPENDIX A

PROPOSED ALTERNATIVE METHODOLOGY FOR ASSESSING THE FALLOUT RADIATION SURVIVABILITY OF TELECOMMUNICATIONS EQUIPMENT

The Office of the Manager, National Communications System (OMNCS) proposed a methodology for assessing the fallout radiation survivability of telecommunications equipment. The developed methodology is described in Fallout Radiation Effects Methodology, dated March 1988. The report illustrates the methodology on the AT&T 5ESS switch. For fallout radiation survivability investigations, full equipment level tests are not feasible as such tests are destructive, and are thus not economically viable. In lieu of this, the methodology proposes to assess equipment survivability based on the survivability of the piece parts that comprise it.

An analysis of the 5ESS switch indicated that it was comprised of 29 piece part technology families (e.g. HMOS, CMOS, and ECL) for which fallout radiation survivability data was available. The data identifies the number of tests, the fallout radiation dosage level, and whether the piece part passed/failed to operate following exposure. The available data was obtained by the OMNCS as part of the AT&T 5ESS Radiation Hardness Assessment Program (RHAP).

The 5ESS switch also contains a number of AT&T proprietary piece parts for which no fallout radiation survivability data is available. Such technology types were not considered in the 5ESS survivability estimate. This has the effect of assuming that such piece part technologies always survive. As the emphasis of the report was to propose a methodology, which was not overly concerned with the accuracy of the 5ESS survivability assessment, the lack of comprehensive data was not a major concern.

Study of the available data on the 29 technology families indicated that certain technology data could be combined with each other. Data was only combined if they could meet the following two criteria:

- The equipment piece parts were of a similar technology

- The survivability data, i.e. the ratio of survivals to samples, of the two technologies were similar.

The reason for combining families of data is to increase the sample sizes of the piece parts. Without significant family piece part sample sizes, a meaningful equipment survivability assessment is not possible as the equipment survivability probability density function (PDF) variance would be too large. Following the combination process of piece part families, the 29 original families were grouped into 15 families.

5ESS switch survivability is obtained by sampling the distributions of the 15 piece part survivability PDFs, where each sample represents the survivability of the particular family. The 15 samples are then multiplied together resulting in an equipment survivability sample. Replicating this process multiple times, in a Monte Carlo fashion, results in a 5ESS switch survivability PDF. Equation 1 defines how equipment survivability is obtained through the sampling of its piece parts:

1.
$$PDF_{equipment} = \Big|_{j=1}^{m} \prod_{i=1}^{n} P_i$$

P = sampled piece part survivability value

n = number of piece part technologies in equipment

m = number of Monte Carlo iterations

Use of this approach results in a conservative equipment survivability assessment. This is because the approach requires each family to survive if the equipment is to survive. This method, basing equipment survivability on the multiplication of survivability samples of its piece part families, adheres to the following assumptions:

- A critical breakdown of switch functionality was not conducted. Therefore all switch piece part families are deemed critical for switch survivability.

- For the equipment to survive, all of its piece part technologies must survive.

- The methodology assumes that each piece part technology is equally critical for switch performance, regardless of how often the technology is present in the switch. Thus, a technology with one piece part in the switch is deemed equally important as a technology with 5,000 piece parts.

- Building protection factors, whereby the building or switch housing may decrease the radiation dosage level on the piece parts, are not accounted for.

Following a nuclear attack, the radiation levels that telecommunications equipment may be exposed to are varied. This methodology proposes using a set of eight arbitrary bins to specify the range of fallout radiation levels that network equipment may be exposed to. The defined bins are as follows:

0-500 Rads (Si)
500-1k Rads (Si)
1k-5k Rads (Si)
5k-10k Rads (Si)

10k-20k Rads (Si)
                    20k-30k Rads (Si)
                    30k-40k Rads (Si)
                    40k-50k Rads (Si)

     In network simulations, the methodology assumes that the
entire network is exposed to one of these eight fallout radiation
bins. Because each equipment in a simulation is assumed to be
exposed to the same fallout radiation level bin, it is called the
uniform fallout radiation exposure level approach. Use of this
approach removes the need to use an approved weapon laydown.
Based on surviving network assets, the point-pair connectivity
metric is calculated via computer models. This metric is a
measure of the post-attack communications capability of the
network compared to the capability of the undamaged network.

     The foundation by which piece part technology survivability
is quantified is test data. The format of the data should
identify the number of piece part technology tests (sample size)
and the number of survivals (i.e. the number of times the piece
part continued to be functional following fallout radiation
exposure). A Bayesian statistical process is then applied to the
data to obtain the piece part technology survivability
distribution. The process originally assumes that nothing is
known about piece part survivability, which is represented by the
noninformative prior distribution. As nothing is assumed to be
known about the piece part survivability, it has an extremely
high variance in its PDF. The test data is then applied to the
noninformative to obtain the posterior distribution. The more
data available, the greater the effect of the data on the
posterior PDF. Therefore high sample sizes result in tight PDFs
(small variances) around the mean, while small sample sizes
result in wide PDFs. This implies that greater confidence is
given to the results of test programs that provide high sample
sizes.

     An example of the PDF survivability for the SRAM piece part
technology at the 500-1k Rad (Si) bin is shown in Figure 1. For
this technology type, the fallout radiation test data stated that
57 of the 59 tests resulted in a survival. A similar
survivability distribution is calculated for each of the other 14
technologies in the 5ESS switch survivability assessment.

     Samples of the SRAM distribution are taken, along with
samples from the distributions of the other 14 defined piece
parts of the 5ESS, and multiplied. Carrying out this routine
multiple times using the Monte Carlo process results in the PDF
of Figure 2. This curve does not represent the actual 5ESS
survivability, but represents the survivability using the OMNCS'
approach without comprehensive test data. The jagged curve is
the switch survivability based on available data.

Figure 1
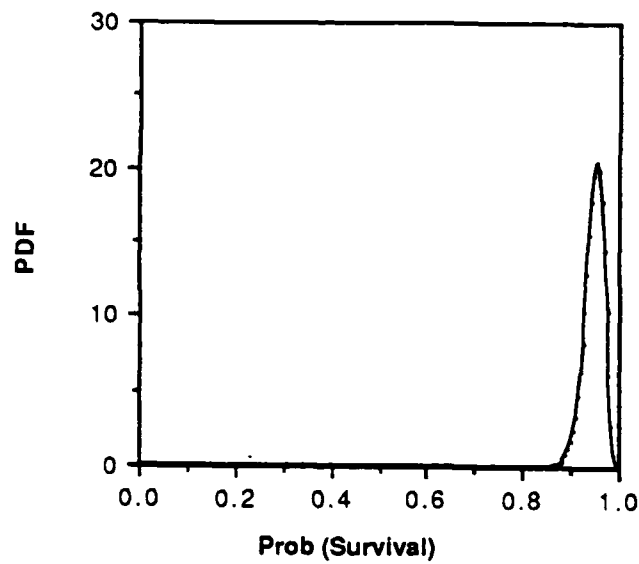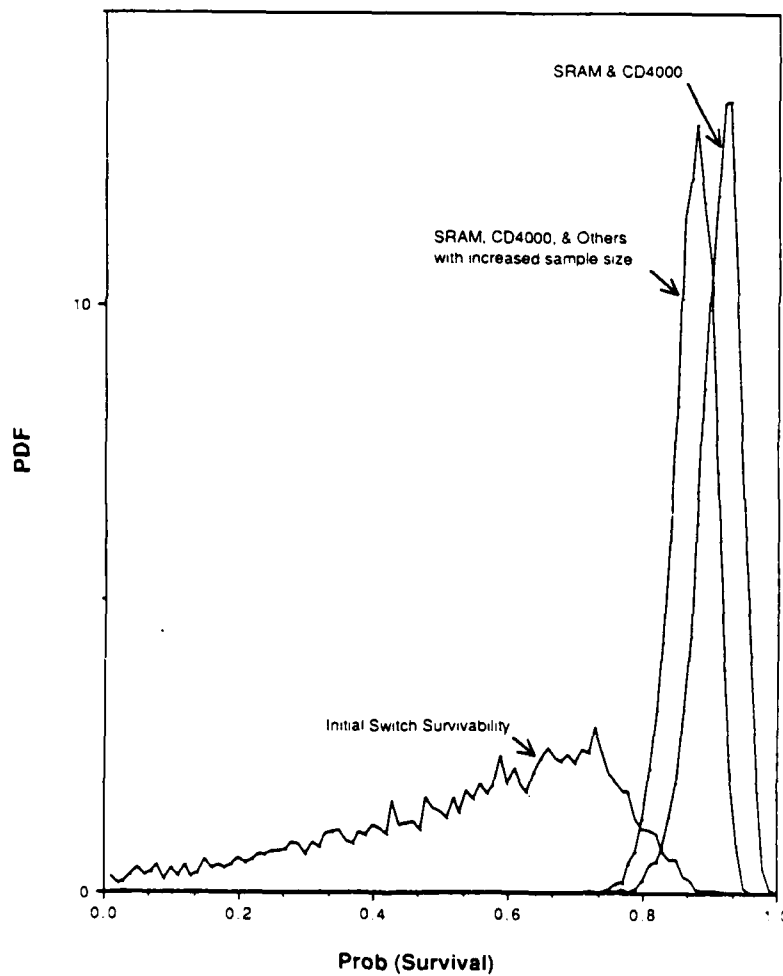## SRAM Piece Part Survivability at 500-1k Rads

Figure 2
Calculated 5ESS Survivability at 500-1k Rads

A-4

The smooth curve of Figure 2 is the switch survivability based on the provided SRAM and CD4000 technology data, plus extrapolated data on all other technologies with an assumed increased sample size. The extrapolated data was obtained by artificially increasing the sample sizes, while maintaining the same survivability to failure ratio. Therefore a 9 pass out of 10 trial data set, may be extrapolated to a set of 90 passes out of 100 trials. The sample sizes are artificially increased to illustrate how larger sample sizes result in a decrease in the variance of the equipment survivability distribution; which implies an increase in the confidence of the equipment level assessment.

AT&T Methodology Concerns

At a meeting held at the AT&T Washington location, on May 26, 1988, AT&T expressed a number of concerns with the proposed equipment level fallout radiation survivability methodology. The four primary concerns are as follows:

- There was not an investigation to assess which piece part technologies were critical to the equipment. For example, if an LED device, which is not critical to switch operation, were to fail, this methodology would assume that the entire switch would fail.

- An analysis was performed on an equipment that did not have comprehensive piece part data. As mentioned earlier, some proprietary technologies did not have any survivability data. AT&T indicated that without data on all technologies, equipment level assessments were too premature.

- The defined fallout radiation level bins do not provide enough fidelity at the expected fallout radiation dosage levels.

- All piece part technologies were considered equal, regardless of their prevalence within the switch.

Both Dr. Andy Rausch of the National Communications System, Technology and Standards (NCS-TS), and Booz, Allen personnel, agree with the AT&T reservations. However, when economics dictate that perfect analyses are not feasible, alternatives must be investigated. Though the alternatives may lead to less accurate results, careful planning can reduce such errors and lead to results that are sufficient for the requirements of the OMNCS.

Concern #1 The OMNCS believes that such critical module assessments of telecommunications equipment are generally too costly. The level of effort that AT&T has indicated necessary

for a detailed circuit pack analysis of the 5ESS switch is beyond the limited resources that the OMNCS has for such a task. The OMNCS acknowledges that by assessing all piece part technologies, whether critical or not, errs toward a conservative equipment survivability assessment. However, such an assessment should provide results that are of sufficient accuracy for the needs of the OMNCS in their emergency telecommunications planning.

Concern #2 The OMNCS agrees with AT&T that there is currently insufficient data to confidently estimate the fallout radiation survivability of the 5ESS switch. However, the report was not intended to quantify 5ESS fallout radiation survivability, rather it was to illustrate a methodology. The report showed how piece part survivability data could be used to quantify telecommunications equipment survivability using the methodology. The 5ESS switch was only used as an example to demonstrate the methodology. Throughout the report, numerous caveats are provided to stress that the OMNCS does not have enough data to confidently predict 5ESS fallout radiation survivability.

Because the 5ESS switch does not play a crucial role within the AT&T toll network, the OMNCS does not plan to sponsor fallout radiation tests on the 5ESS piece parts which do not have available data. When the OMNCS supports analysis on more critical toll level switches, such as the AT&T 4ESS and the Northern Telecom DMS-100 switches, all of their equipment piece parts should have fallout radiation survivability data. Therefore critical network equipment should have their full range of piece parts addressed in their survivability assessments. In addition, data collected on the 4ESS program may be applicable for enhancing the 5ESS survivability assessment, as AT&T personnel indicated that common proprietary piece parts are often used on both switches.

Concern #3 The OMNCS agrees with AT&T, in that additional review is warranted before the bin ranges are finalized. As the report was a methodology, the exact ranges of the bins were not that important. The bin level ranges will be important when full-scale equipment level and network level fallout radiation studies are conducted. The OMNCS plans on conducting additional analysis to develop bin ranges that reflect expected fallout radiation dosage levels at equipment locations following nuclear attack.

Concern #4 Dr. Andy Rausch proposed a modified methodology which accounts for the relative quantities of equipment piece parts. The piece part survivability PDFs are convoluted together to calculate the equipment survivability PDF. This modified methodology is the subject of the rest of this paper.

Modified Methodology

At the May 26 meeting, Dr. Andy Rausch presented a modification to the methodology which takes into account the number of various piece part technologies within telecommunications equipment. The modified method actually performs a convolution of all the piece part family survivability PDFs to obtain the equipment survivability PDF, as shown in Equation 2.

2. $PDF_{equipment} = PDF_1 * PDF_2 * PDF_3 \ldots PDF_n$

$PDF_{equipment}$ = Equipment survivability PDF

PDF_n = PDF of the n individual piece part families

This approach results in allowing technologies which are most prevalent in the equipment to have a greater impact on equipment survivability than those that occur less frequently. Specifically, the relationship is linear. Therefore, a technology with 10,000 piece parts in an equipment has 10 times the impact on equipment survivability relative to a technology represented by 1,000 piece parts.

An example application of this approach for a hypothetical telecommunications equipment that is composed of only two piece part technologies is now presented. Figure 3 illustrates the survivability of hypothetical Technology A which has 2,000 piece parts in the equipment. The X-axis represents the number of piece parts within the equipment that survive the fallout radiation exposure. Because theoretically, any number of the 2,000 piece parts could survive, the X axis ranges between 0 and 2,000. The shape of the PDF curve is dependent on the test data. Assume the data states that the technology survived 21 of 30 tests. Because the data indicates that 70 percent of technology A's piece parts survived, the mean value of Figure 3 is centered at 1,400 (70 percent of 2,000). Figure 4 shows survivability of the second hypothetical technology, Technology B, which is represented by 1,000 piece parts in the equipment. Assume that Technology B has 10 test data samples, and survived 6 of the tests. The X-axis of Figure 4 ranges between 0 and 1,000, with a mean of 600. Note that the variance of the Technology B survivability curve is greater than that of Technology A because of its smaller test data sample size.

Assuming that a switch is only comprised of these two technologies, switch survivability is obtained by a convolution of the two technologies. The resulting convolution is shown in Figure 5. The X-axis ranges between 0 and the sum of all the piece part technologies in the switch, which in this example is 3,000. The mean of the equipment survivability is 2,000, which is the sum of the Technology A and B survivability means, 1,400

and 600. Normalizing the switch survivability to a probability value results in an assessment in the form shown in Figure 6. As the total mean piece part survivability is 2,000 of 3,000, the mean switch survivability rate is .67.

This modified methodology assumes that an equipment fails at the rate that its piece parts fail. Therefore if 10 percent of the piece parts fail, the equipment has a 10 percent chance of failing. Likewise, if 50 percent of the piece parts fail the switch still has a 50 percent chance of surviving. This approach may lead to optimistic survivability results. Using the analogy of an automobile, if 50 percent of its parts were out of service, most people would probably feel that the automobile would have a very slim chance of still operating. Yet the modified methodology would still give the automobile a 50 percent chance of survival. However, because telecommunications equipment (particularly switches) often have redundant components on critical components, this approach may still be appropriate for use by the OMNCS.

However, the original methodology may be too conservative. For if a technology that is based in non-critical modules fails, it should not affect switch operability. Yet the original method would assume a failure possibility. These examples illustrate the liabilities of the two methods for assessing equipment survivability to fallout radiation exposure. The original method is rather conservative while the modified method may be too optimistic. Because neither method considers building protection factors and component redundancy, the modified method may be more accurate. The OMNCS will pursue additional investigation before either of these methods, or perhaps a third method, are officially adopted.
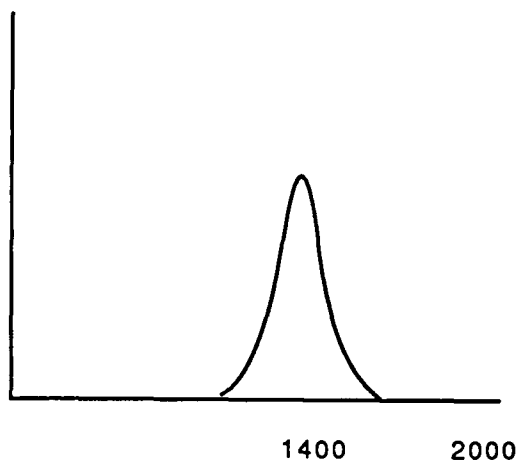
Figure 3
Survivability PDF of Technology A

1400   2000

Figure 4
Survivability PDF of Technology B

600   1000
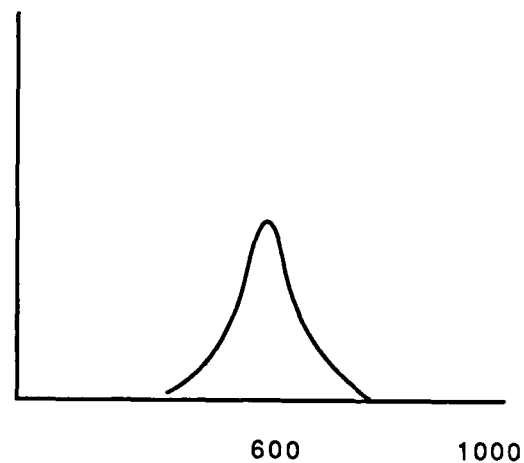
Figure 5
Convolution of Technology Data to Estimate Equipment Survivability

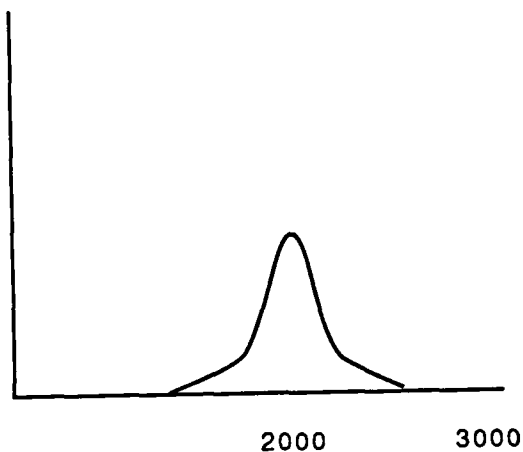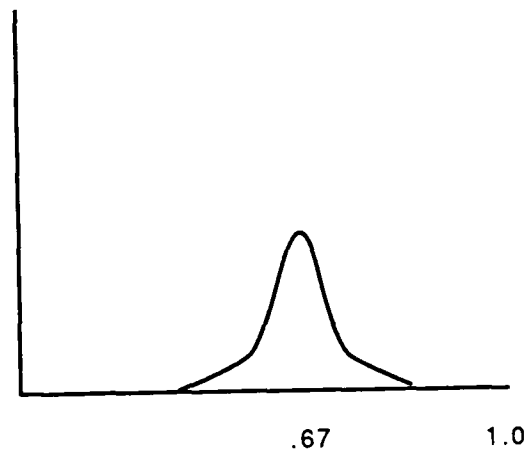2000   3000

Figure 6
Normalized Equipment Survivability PDF

.67   1.0

* These curves do not correspond to an application of the BSM on actual data, their sole purpose is to illustrate the convolution of piece part data into equipment survivability estimations.

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